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ECONOMIC BENEFITS OF IMPROVED INFORMATION  
ON WORLDWIDE CROP PRODUCTION

An Optimal Decision Model of Production  
and Distribution with Application  
to Wheat, Corn, and Soybeans



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**FINAL**

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ON WORLDWIDE CROP PRODUCTION

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and Distribution with Application  
to Wheat, Corn, and Soybeans

Prepared for  
The National Aeronautics and Space Administration  
Office of Applications  
Washington, D.C.

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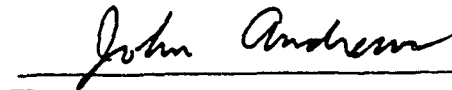
## NOTE OF TRANSMITTAL

This report is prepared for the National Aeronautics and Space Administration, Office of Applications, under Contract NASW-2558.

The methods developed in this report for estimating benefits of improved information are the best ECON is aware of at the time of writing. However, the subject is immensely complex, and it is possible that later work will improve on the methods, the accuracy of the inputs and of the results. ECON has maintained a conservative viewpoint on potential economic benefits of improved information, so that the estimates presented are more likely to be on the low side than the high side.

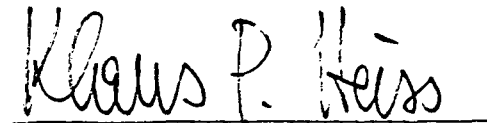
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Submitted by:



John Andrews  
Principal Investigator

Approved by:



Klaus P. Heiss  
Project Director

## ABSTRACT

An optimal decision model of crop production, trade and storage has been developed for use in estimating the economic consequences of improved forecasts and estimates of worldwide crop production. The model extends earlier ECON "distribution benefits" models to include "production effects" as well. Application to improved information systems meeting the goals set in the Large Area Crop Inventory Experiment (LACIE) indicates annual benefits to the United States of \$200 to \$250 million for wheat, \$50 to \$100 million for corn, and \$6 to \$11 million for soybeans, using conservative assumptions on expected LANDSAT system performance

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## 1. INTRODUCTION

### 1.1 Background of Study

This report represents a culmination of several years of work at ECON, Inc. in the area of economic benefits of improved information on agricultural crops. Previous ECON work is documented in References 1 through 8. In these reports, ECON has pursued two separate lines of study of the problem. One line is primarily descriptive, involving the analysis of various time series of agricultural statistics, and using econometric techniques to determine the behavioral relationships between forecast accuracies on the one hand and prices, production, exports, and stocks on the other hand. With this approach, conclusions are obtained on the impact of improved information on the operation of the commodity markets, and straightforward economic analysis is then applied to estimate benefits to the United States.

The second line of study is partly normative. Rather than simply observing how commodity markets have operated under past conditions, one assumes that decisions under any conditions of information are made in accordance with economic objectives. Thus, one builds a mathematical model of decision making to describe the response of production, stocks, and exports to information and changes in information. Using standard economic models of demand and supply, calibrated to historical data, one then translates these responses into economic benefits to various market agents in the United States and elsewhere. In previous reports [1, 2, 3 and 6], ECON has studied distribution benefits of improved information in this way. The benefits estimated have been based on more efficient spatial and temporal distribution of agricultural commodities, on the assumption that the quantities produced are unchanged under the conditions of improved information.

In the present report, we present a study of production and distribution benefits of improved information, using an extension of the distribution benefits model presented in References 1 and 2. The model describes crop production and distribution at a high level of aggregation. The trading units are the United States and the aggregated rest of the world. Trade among the various regions making up the rest of the world is not considered.

## 1.2 General Assumptions and Method

The model is applied in this study to wheat, corn and soybeans, analyzing information improvements expected from the use of LANDSAT. We assume that LANDSAT will be only part of an information system which prepares regular forecasts and estimates and makes them public simultaneously in all regions.

This is a most realistic assumption. Crop information cannot be restricted "to the United States only." For U.S. farmers, traders and consumers to make best use of crop information means--*ipse facto*--making it public. What some may mean by restricting global crop information "to the United States only" is to restrict such knowledge to a few government officials, a most difficult and probably wasteful task, given the subject matter.

Two principles are used in evaluating such information: first, that it will be available to all agents including consumers, producers and traders in free competitive markets; and second, that the economic value of a commodity is measured by the willingness of consumers to pay for it.\*

In the mathematical model, the global process of crop production and distribution is viewed as a control process, in which rates of consumption,

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\* For an analytically thorough statement of the economic value measures used in this report see D. F. Bradford and H. H. Kelejian [6] to be published in the Review of Economics and Statistics.

planting and exports are control variables, and estimates of supply in the two producing units are state variables. Analysis of this control process is accomplished through the methodology of dynamic programming. In dynamic programming, solution of a functional equation called the optimality principle leads to an explicit statement of optimal decision or control policy, together with the value function, which gives the economic value obtained by use of the optimal decision policy. The model determines the value of improved information by comparing the value functions obtained through dynamic programming for the alternative information systems.

### 1.3 Overview of the Decision Model

#### 1.3.1 The System to be Modeled

Our model is an idealized description of the process by which successive annual crops of varying sizes are produced throughout the world and then distributed to consumers at different times and places. Thus, we are modeling the activities of crop production, inventory management, and international trade. The various market agents performing these activities can be classed as farmers or producers, speculators, inventory holders, exporters, importers, and so on. Our model describes the decision making of these agents and its consequences over an extended time period.

#### 1.3.2 Dynamic Control Process

A basic feature of our model is that it is dynamic; that is, that it explicitly treats changes of its fundamental variables through time. In fact, it has been found important for the problems under study to model an extended time period of many years, and to build a formal structure that leads to practical calculations for any time horizon. This has been accomplished in the present work, which incorporates an infinite time horizon.

A fundamental simplifying principle used in this model is that all decisions are made through the operation of a free market, so that production, exports, and inventories take on levels permitting no further investments or transactions producing a positive mean present value. This assumption is made for the current as well as the improved crop information systems. The exclusion of such arbitrage opportunities amounts to the exclusion of opportunities for increasing the sum of mean economic value to all market agents. Thus, the free market assumption implies that the aggregate decisions are optimal in the sense of maximizing this sum of mean economic value. Because these aggregate production, trade and inventory holding decisions are optimal, we need not model the decision making of the individual market agents such as farmers and exporters. Instead, we model the system as if each consuming and producing unit were controlled by one rational individual, consciously seeking the maximization of total mean economic value.\*

Though we do not model the decision making of individual market agents, we do model the economic consequences of these decisions to the various classes of market agents. For instance, we determine such quantities as total U.S. exports, total costs incurred by producers, net revenues to traders, etc.

Our model takes the form of a dynamic control process. The system of production, distribution, information use, and consumption is described by time-dependent state variables, control or decision variables, and a state transformation. An overview of this model is given in Figure 1.1.

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\* This is a generally valid insight for competitive market economies, equivalent to complete information in centrally planned economies. For an overview on this issue see Kenneth Arrow "Limited Knowledge and Economic Analysis" [9].

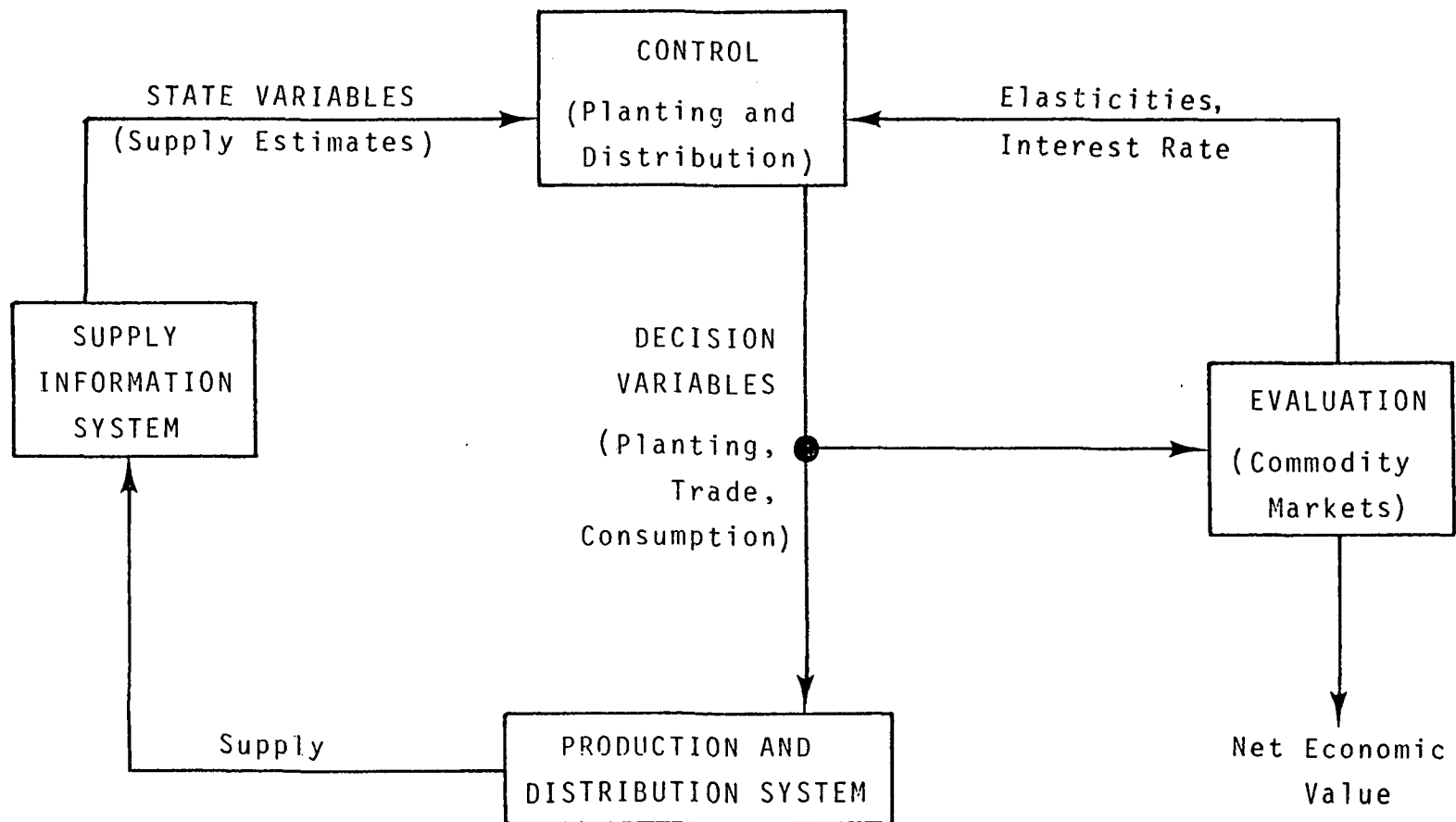


Figure 1.1 Overview of Dynamic Control Process

The block at the bottom of this diagram describes the production and distribution system itself, which is partially controlled by the decision variables: planting, exports, and consumption. The state of this system at any time is the supply (stocks and growing crop), which is represented as the output arrow left of the block. The control of the system is only partial, since yield is uncertain. Consequently, the state of the system is uncertain; it (supply) is not automatically known. The information system, diagrammed at the left of the figure, produces supply estimates. These supply estimates at any given time form the state variables of the model. Decisions are made in the light of the supply estimates coming from the information system, and the economic data evident in the commodities markets. In particular, the value produced by making one decision or another can be determined from the elasticities of production, demand and transportation, and the interest rate (for determining cost of storage). This economic value calculation is both a part of the decision or control process, and the source of the basic output of the model, shown as the output arrow of the rightmost block in Figure 1.1.

#### 1.4 Organization of Report

A statistical characterization of information systems is used in Chapter 2 to generate inputs to the model. Chapters 3 and 4 present the mathematical details of the optimal decision model. In Chapter 3, it is presented in a simplified form, treating only one producing unit rather than two. The structure and results of this simplified version are of some interest in their own right, but this chapter is included primarily to facilitate the reader's understanding of the model. The methods of reasoning and calculating are not difficult, but they are perhaps somewhat unfamiliar to those who have



not worked extensively with dynamic programming. Chapter 4 presents all of the modeling concepts and computational tools used in the full model, but with a minimum of complexity. Illustrative results are also included.

Chapter 5 contains the results of applying the model to the problem of estimating potential LANDSAT benefits associated with production information on wheat, corn and soybeans. The calculations were performed using a program written in APL and run on the IBM 370 at Princeton University and the Amdahl 470 at Scientific Time Sharing Company.

## 2. CHARACTERIZATION OF THE INFORMATION SYSTEMS

In order to determine the numerical value of specific improvements in worldwide crop production information, we need numerical descriptions of both the current estimating and forecasting capability and the specific improved capability under analysis. Our numerical description of the current capability is based on a statistical analysis of published estimates and forecasts over the past 14 years. Our numerical description of the improved capability is in the form of accuracy projections. That is, we hypothesize the achievement of specific accuracy goals at specific times of year for estimates of United States and worldwide crop production. At the time of this writing, these accuracy projections are essentially targets which various researchers might consider adopting in their system design (LACIE). When different estimates of expected system performance are available from these researchers, the model described here will be able to determine the economic benefits associated with those estimates.

### 2.1 Statistical Method

To construct a statistical description of the performance of an existing crop production information system, we begin with a table of published forecasts. In Tables 2.1 and 2.2 are given 14 years of monthly wheat production estimates for the United States and for the aggregated rest of the world respectively. The sources of these data are discussed in Appendix A2.

As in the case of improved information, only public information is included in the assessment of the current information system. The best available sources of such information were used. Foremost among these are the

Table 2.1 U.S. All Wheat Production Estimates,  
June, August, October, December, and  
Final, millions of bushels

Year	June 1	August 1	October 1	December 1	Final
1961	1343	1204	1211	1235	1232
1962	1058	1063	1095	1092	1092
1963	1084	1151	1133	1137	1147
1964	1213	1285	1286	1290	1283
1965	1283	1376	1354	1327	1316
1966	1235	1286	1296	1311	1305
1967	1550	1511	1554	1524	1508
1968	—	1606	1598	1570	1557
1969	—	1459	1456	1459	1443
1970	—	1357	1360	1378	1352
1971	—	1601	1628	1640	1618
1972	—	1543	1559	1545	1545
1973	—	1717	1727	1711	1705
1974	—	1840	1781	1793	1796

Source: Statistical Reporting Service (USDA) Summarizations of Crop Production. See Appendix A2.

Table 2.2 Aggregate Rest of the World Wheat  
Production Estimates, June, August,  
October, December, February, and  
Final, millions of metric tons

Year	June	August	October	December	February	Final
1961	178.75	178.75	178.75	178.75	177.32	143.30
1962	183.76	185.04	172.74	172.74	172.74	153.15
1963	182.90	188.47	202.35	202.06	204.06	184.18
1964	192.19	192.62	201.63	200.63	205.92	165.02
1965	189.05	190.91	193.77	193.77	201.20	194.48
1966	195.91	201.20	208.49	207.21	204.78	177.03
1967	199.34	199.77	208.35	208.64	209.78	231.23
1968	210.64	215.93	215.07	231.66	228.09	201.77
1969	218.65	218.65	227.37	231.37	230.80	237.67
1970	242.81	242.81	243.39	245.96	246.25	215.22
1971	235.52	235.52	227.66	243.39	240.24	224.37
1972	250.82	250.82	260.26	259.12	257.54	245.67
1973	253.68	254.11	264.69	265.12	270.27	255.68

Source: ECON calculation based on Grain Bulletin data: See Appendix A3.

Grain Bulletin of the Commonwealth Secretariat in London, U.K., and publications by the Foreign Agriculture Service of the USDA.

Tables such as 2.1 and 2.2 provide a matrix of estimates which we can denote  $F = \{F_{ij}\}$ . In our applications,  $F$  is a  $13 \times 6$  matrix, but in the following discussion, we will leave the shape general, so  $F$  is assumed to have  $m$  rows and  $n$  columns. As is clear from Tables 2.1 and 2.2, the wheat production system has been growing, so that the numbers in the bottom rows of  $F$  are considerably larger than in the top of  $F$ . Since we want to use all of  $F$  in the statistical analysis, but apply the results to a future time (when LANDSAT is operational), some kind of normalization is required. Most likely, the wheat production system will continue to grow in the future, but it is difficult to predict whether the growth rate will be as great as in the recent past. We take a conservative position in this study, by assuming the system will operate in a steady state, at a scale corresponding to the present time. Thus, we begin by normalizing the tables, dividing each estimate by the final estimate for its crop year. Algebraically, we replace  $F$  with

$$N = \{N_{ij}\},$$

where

$$N_{ij} = \frac{F_{ij}}{F_{im}}, \quad i=1, \dots, m, \quad j=1, \dots, n.$$

Tables 2.3 and 2.4 give these normalized estimates. We will determine mean squared errors in this dimensionless form, and then multiply them by the squares of the current typical United States and rest of the world annual wheat production figures, which are approximately 50 million metric tons and 300 million metric tons respectively.

Table 2.3 Normalized U.S. Wheat Production Estimates

Year	June	August	October	December	Final
1961	1.090	0.977	0.983	1.002	1
1962	0.069	0.973	1.003	1	1
1963	0.945	1.003	0.988	0.991	1
1964	0.945	1.002	1.002	1.005	1
1965	0.975	1.046	1.029	1.008	1
1966	0.946	0.985	0.993	1.005	1
1967	1.028	1.002	1.030	1.011	1
1968	--	1.031	1.026	1.008	1
1969	--	1.011	1.009	1.011	1
1970	--	1.004	1.006	1.020	1
1971	--	0.989	1.006	1.014	1
1972	--	0.999	1.009	1	1
1973	--	1.007	1.013	1.003	1
1974	--	1.024	0.992	0.998	1

Source: ECON, Inc.

Table 2.4 Normalized Rest of the World  
Wheat Production Estimates

Year	June	August	October	December	February	Final
1961	1.166	1.166	1.166	1.166	1.157	1
1962	1.120	1.208	1.128	1.128	1.128	1
1963	0.993	1.023	1.098	1.097	1.108	1
1964	1.165	1.167	1.222	1.216	1.248	1
1965	0.972	0.982	0.996	0.996	1.035	1
1966	1.107	1.137	1.178	1.170	1.157	1
1967	0.862	0.864	0.901	0.902	0.907	1
1968	1.044	1.070	1.066	1.148	1.130	1
1969	0.920	0.920	0.957	0.973	0.971	1
1970	1.128	1.128	1.130	1.143	1.144	1
1971	1.050	1.050	1.015	1.085	1.048	1
1972	1.021	1.021	1.060	1.055	1.048	1
1973	0.992	0.994	1.035	1.037	1.057	1
1974	0.920	0.920	0.911	0.975	0.976	1

Source: ECON, Inc.

Calculating from the data in Tables 2.3 and 2.4, we find that the variance of the first, or June, estimate is 6.39 (million tons)<sup>2</sup> in the United States and 895 (million tons)<sup>2</sup> in the rest of the world. The root mean squared "errors" of the various estimates are as shown in Table 2.5. These are based on the assumption that the final estimates are correct. In fact, we must assume that some residual error is present in these final estimates. In the rest of the world, the residual error is probably substantial; while in the United States, it might be quite small.\*

The error in the published United States forecasts decrease through the crop year, while those in the rest of the world remain essentially constant. According to Table 2.5, the errors in the rest of the world actually increase slightly over time through the crop year. Although this increase is a property of the published data, it can not be a property of the information used for rational judgements in the commodity markets. If the estimates published in June are known to be superior to those published later (on the average), the later ones will be ignored. Thus, we take the error of the June estimate (10.69 percent) as holding throughout the crop year, until the beginning of the final period (April), at which time we assume the market acts as if the true production is known. This assumption favors the stated performance of the current crop information system.

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\* In the United States the Bureau of the Census makes every five years an independent estimate of United States crops. These estimates differ from USDA final estimates (one year after preliminary final estimates) often by several percentage points for most crops. Definitions, samples and measures used differ in the two cases, as one would expect. This goes to show that even for the United States, it is difficult to determine precisely the performance of the current crop information system. In the interest of a conservative assessment, USDA final estimates are assumed in this study to be error free.



Table 2.5 Error Statistics on Published Wheat Production Estimates

	United States		Rest of World	
	%	Millions of Tons	%	Millions of Tons
June Estimate-- Year-to-Year Variation				
Standard Deviation	5.06	2.53	9.97	29.91
Root Mean Squared Errors (Forecast Minus Final)				
June	5.26	2.63	10.69	32.07
August	1.97	.985	11.15	33.45
October	1.57	.785	11.35	34.05
December	0.88	.44	11.76	35.28
February	--	--	11.90	35.7
Source: ECON, Inc.				

For our benefits analysis, the useful form of the description of information system performance is the sequence,  $\sigma_j^2$ , of variance of month-to-month changes in annual production estimate. We form the successive differences

$$\sigma_j^2 = V_{j-1} - V_j$$

where  $V_j$  is the mean squared error in the monthly estimates. The first  $\sigma_j^2$ , corresponding to June, is the variance of the June estimate itself, not of its error. Thus, the sum of the six  $\sigma_j^2$ 's represents the a priori variance of the annual wheat production, while the sum

$$\sum_{j>J} \sigma_j^2$$

represents the remaining variance after obtaining information at time  $J$ .

Table 2.6 gives the mean squared errors ( $V_j$ ) and the difference variances ( $\sigma_j^2$ ) for the United States and the rest of the world.

## 2.2 Improved (LACIE) Crop Information Systems

The LACIE 90/90 goal can be interpreted as the achievement of estimates of wheat production at harvest with standard error 6 percent. Since the system can be expected to produce steady improvements in accuracy through the entire worldwide growing and harvest period, we use a linear decline model for the progression of mean squared error over time. Improvements begin for the rest of the world with the June 1 forecast. The next estimate, August 1, has standard error 6 percent, and improvements continue period by period until the true production is discovered April 1, the beginning of the final period. Figure 2.1 gives a graph of our assumptions on mean squared error for three cases--6 percent at August 1, 3 percent at August 1, and 9 percent at August 1. We view the 6 percent case as roughly equivalent to

Table 2.6 Forecast Difference Variances for Current Information System, United States and Rest of the World Wheat Production (in millions of metric tons squared)

Month	United States		Rest of the World	
	MSE = Mean Squared Error	$\sigma^2$ = Differences Between Successive MSE	MSE = Mean Squared Error	$\sigma^2$ = Differences Between Successive MSE
June	6.920 <sup>(1)</sup>	6.390 <sup>(2)</sup>	1028 <sup>(1)</sup>	895 <sup>(2)</sup>
August	.970 <sup>(1)</sup>	5.950	1028 <sup>(1)</sup>	0
October	.616 <sup>(1)</sup>	.354	1028 <sup>(1)</sup>	0
December	.192 <sup>(1)</sup>	.424	1028 <sup>(1)</sup>	0
February	.192 <sup>(1)</sup>	0	1028 <sup>(1)</sup>	0
April	0 <sup>(1)</sup>	.192 <sup>(1)</sup>	0 <sup>(1)</sup>	1028 <sup>(1)</sup>

Notes:

<sup>(1)</sup> Residual error variance to be added to this figure.

<sup>(2)</sup> The June  $\sigma^2$  is the year-to-year variance of June production estimates.

Source: ECON, Inc.

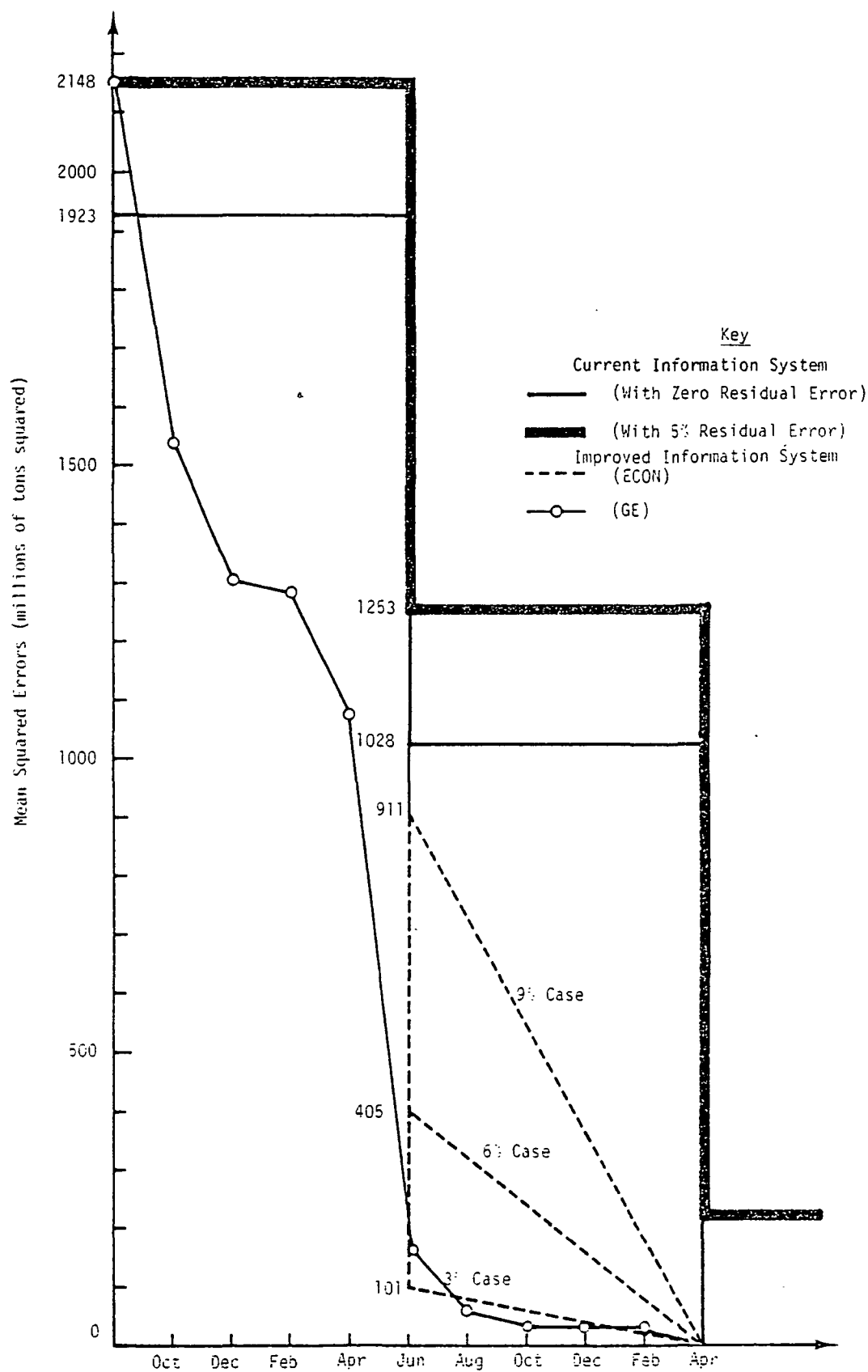


Figure 2.1 Mean Squared Error Models for Rest-of-World Wheat Production Estimate

LACIE targets. The 3 percent case is assumed to correspond to a much better capability, and the 9 percent case is included to represent the possibility that LACIE targets cannot be achieved completely.

The above assumptions lead to forecast difference variances ( $\sigma_j^2$ ) as given in Table 2.7, in the form required for input to the benefit calculations. An alternative approach to the modeling of the information is based upon the General Electric "Sigma Squared" study [11]. Details of this approach are to be found in the G.E. final report. ECON received the standard errors (as percent of final) for wheat production estimates in 12 countries and, on the basis of these values, calculated the required inputs ( $\sigma_j^2$ ) to the benefit calculation.

### 2.3 General Electric's "Sigma Squared" Study of Improved Crop Information Systems

Table 2.8 gives the GE projection of LANDSAT performance for the United States and for eleven major foreign wheat producers. The earliest forecasts referenced in these data are in September for Italy, October for the United States, the United Kingdom and the U.S.S.R. The earliest forecasts for other countries occur at various times up to May. For our analysis, we must assume that the worldwide wheat markets operate with some estimate of production prior to these dates, and we must estimate its standard error. For this purpose, we use the results of our analysis of the current (nonsatellite) information system. According to that analysis, the standard error of the forecast of wheat production for the aggregate rest of the world (other than the United States) is 11.8 percent in June and after, and 15.5 percent before June. Assuming that the mean squared error is distributed among major regions in proportion to their average production, this leads to percent

Table 2.7 Forecast Difference Variances for Improved Information Systems,  
Rest of World Wheat Production (in millions of metric tons squared)

Month	6% Case		3% Case		9% Case	
	Mean Squared Error	$\sigma^2$	Mean Squared Error	$\sigma^2$	Mean Squared Error	$\sigma^2$
Jun	405	1743	101.25	2046.75	911.25	1236.75
Aug	324	81	81	20.25	729	182.25
Oct	243	81	60.75	20.25	546.75	182.25
Dec	162	81	40.50	20.25	364.50	182.25
Feb	81	81	20.25	20.25	182.25	182.25
Apr	0	81	0	20.25	0	182.25

Table 2.8 General Electric Projection of LANDSAT Performance

Country	Standard Error of Production Estimate by Country, percent																				
	Forecasts in Advance of Crop Year										Estimates During Crop Year										
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
United States	---	8.8	8.7	8.7	8.7	8.7	7.5	6.2	5.1	3.9	3.0	---	---	---	---	---	---	---	---	---	---
Canada	---	---	---	---	---	---	---	---	11.3	9.3	7.4	5.5	3.8	---	---	---	---	---	---	---	---
Australia	---	---	---	---	---	---	---	---	18.8	18.7	16.9	16.1	13.5	11.1	8.6	6.1	3.9	---	---	---	---
Argentina	---	---	---	---	---	---	---	---	11.7	10.9	10.7	10.4	9.2	8.0	6.9	5.9	5.0	---	---	---	---
Italy	12.3	12.3	12.3	12.3	12.3	12.3	12.3	10.4	8.7	7.2	5.7	4.4	---	---	---	---	---	---	---	---	---
China (P.R.)	---	---	---	---	---	---	---	5.6	5.3	4.9	4.4	4.0	3.7	---	---	---	---	---	---	---	---
France	---	---	---	---	---	---	---	---	11.9	9.8	7.7	5.8	4.1	---	---	---	---	---	---	---	---
India	---	---	10.6	10.2	8.9	7.2	5.7	4.6	3.9	---	---	---	---	---	---	---	---	---	---	---	---
United Kingdom	---	12.1	12.0	12.0	12.0	12.0	12.0	10.7	9.4	8.1	6.9	5.8	4.8	---	---	---	---	---	---	---	---
South Africa	---	---	---	---	---	---	11.9	11.8	11.8	11.8	10.4	8.8	7.8	6.5	5.3	4.2	---	---	---	---	---
Spain	---	---	11.9	11.8	11.8	10.4	9.1	7.7	6.4	5.2	4.1	---	---	---	---	---	---	---	---	---	---
U.S.S.R.	---	14.7	14.7	14.6	14.6	14.6	14.4	12.4	10.4	8.4	6.5	4.6	3.6	---	---	---	---	---	---	---	---

errors by countries (for the current system) as shown in Table 2.9. The entries in Table 2.9 are calculated as follows. If  $t$  is the fraction of rest of the world wheat production corresponding to a major region, and if  $E$  is the fractional standard error in the estimate of rest of the world production, then the mean squared error for the region is  $tE^2$ , so the fractional standard error for the region is

$$\sqrt{\frac{tE^2}{t}} = \frac{E}{\sqrt{t}} .$$

For Table 2.9, this formula is used with  $E = .155$  (before June) and  $E = .118$  (June and after). Combining these figures with those of Table 2.8, we obtain accuracies by country for the improved information system as shown in Table 2.10.

The statistical description of an information system required for calculation of economic benefits is in the form of the sequence of variances (in millions of metric tons squared) of period-to-period changes in the production estimates for the United States and the aggregated rest of the world. Using the figures of Table 2.10, together with the average annual wheat production of 50 million metric tons in the United States and 300 million metric tons in the rest of the world, we obtain the sequences of variances given in Table 2.11. Since our economic benefits model uses time periods of two-month duration, the differences in the last column of Table 2.11 are based on alternate columns of Table 2.10. Also presented in Table 2.11, for comparison purposes, are the forecast difference variances for the current and the linear model (6 percent case) improved information systems.

We observe in Table 2.11 that the effect of the General Electric calculations on the rest of world statistical description is to move some of the



Table 2.9 Accuracy of Current Production  
Information System by Major Region

Region	Fraction of R.O.W. Wheat Production	Fractional Standard Error of Estimate	
		Before June	June and After
U.S.S.R	.310	.277	.212
Argentina, South Africa, Australia	.058	.639	.490
China, India	.171	.372	.285
U.K., France, Spain, Italy	.114	.456	.349
Canada and Remainder	.347	.261	.200

Table 2.10 LANDSAT System Performance by Country and R.O.W. Aggregate

Country	Standard Error of Production Estimate, percent																	
	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.
United States	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	6.2	5.1	3.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Canada	26.1	26.1	26.1	26.1	26.1	26.1	26.1	11.3	9.3	7.4	5.5	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Australia	63.9	63.9	63.9	63.9	63.9	63.9	63.9	18.8	18.7	16.9	16.1	13.5	11.1	8.6	6.1	3.9	3.9	3.9
Argentina	63.9	63.9	63.9	63.9	63.9	63.9	63.9	11.7	10.9	10.7	10.4	9.2	8.0	6.9	5.9	5.0	5.0	5.0
Italy	12.3	12.3	12.3	12.3	12.3	12.3	10.4	8.7	7.2	5.7	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
China	37.2	37.2	37.2	37.2	37.2	37.2	5.6	5.3	4.9	4.4	4.0	3.7	3.7	3.7	3.7	3.7	3.7	3.7
France	45.6	45.6	45.6	45.6	45.6	45.6	45.6	11.9	9.8	7.7	5.8	4.1	4.1	4.1	4.1	4.1	4.1	4.1
India	37.2	10.6	10.2	8.9	7.2	5.7	4.6	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
United Kingdom	12.1	12.0	12.0	12.0	12.0	12.0	10.7	9.4	8.1	6.9	5.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
South Africa	63.9	63.9	63.9	63.9	63.9	11.9	11.8	11.8	11.8	10.4	8.8	7.8	6.5	5.3	4.2	4.2	4.2	4.2
Spain	45.6	11.9	11.8	11.8	10.4	9.1	7.7	6.4	5.2	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
U.S.S.R.	14.7	14.7	14.6	14.6	14.6	14.4	12.4	10.4	8.4	6.5	4.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Aggregate R.O.W.	13.1	12.0	12.0	12.0	11.9	11.8	10.9	5.3	4.4	3.5	2.7	2.0	2.0	2.0	2.0	1.9	1.9	1.9

Table 2.11 Statistical Description of Current and Improved Forecast Difference Variances						
Period	(millions of metric tons) <sup>2</sup>					
	Current System		Linear Model (6% Case)		G.E. Sigma Squared	
	U.S.	R.O.W.	U.S.	R.O.W.	U.S.	R.O.W.
Prior - June	0	0	0	0	0	0
Jun. - Aug	0	0	0	0	0	0
Aug. - Oct.	0	0	0	0	0	607
Oct. - Dec.	0	0	0	0	0	237
Dec. - Feb.	0	0	0	0	0	19
Feb. - Apr.	0	0	0	0	3.70	210
Apr. - Jun.	6.39	895	6.39	1743	5.81	900
Jun. - Aug.	5.95	0	5.95	81	1.55	111
Aug. - Oct.	.354	0	0.354	81	0	28
Oct. - Dec.	.424	0	0.424	81	0	2
Dec. - Feb.	0	0	0	81	0	0
Feb. - Final	.192	1253	0.192	81	2.25	34
Total	13.31	2148	13.31	2148	13.31	2148

forecast difference variances to an earlier time of the year. The sum of the variances remains the same, and represents the prior uncertainty in production. But with the G.E. information systems, some of this uncertainty is resolved sooner than with the current information system.

The choice of a "correct" model of the improved information system depends ultimately on a number of unknowable quantities (at this time). Empirical data on performance of a LANDSAT system in R.O.W. countries would be one prerequisite. Another would be a much more thorough knowledge of the variation of wheat harvests due to weather and cultural practice than is currently available. In the meanwhile, we are obliged to relate the economic benefits of improved wheat information to the statistical description of the information system in a partially parametric way, but guided by (1) the LACIE goals, (2) our analysis of the consequences of adopting those goals and (3) the General Electric "Sigma Squared" study results. In a later chapter we will explore the sensitivity of the benefits to the choice of statistical description of the improved information system.

### 3. SIMPLIFIED PRODUCTION AND DISTRIBUTION MODEL

#### 3.1 Structure

The following is a description of an infinite horizon model of crop production and storage. For the utmost simplicity, only one producing unit is modeled, and the year is divided into only two periods. The timing assumptions of the model are as shown in Figure 3.1.

At time 1, the beginning of period 1, the state of the system is represented by a scalar state variable,  $x$ .  $x$  refers to the mean value at time 1 of total stocks, including the newly available production (still uncertain) and the carryover from the previous year (known). During period 1 of each year, decisions are made on period 1 consumption and on planting. These decisions depend only on  $x$ , and are made so as to maximize the discounted mean present value of consumer gains plus producer gains from the present indefinitely into the future. This maximization depends on assumptions about future planting and consumption decisions--it is assumed that these are made according to the same maximization criterion. As time advances from time 1 to time 2, information is obtained possibly leading to a revision of the estimated supply. Also during this time interval, the planting of a quantity  $Y_2$  is accomplished and the consumption of a quantity  $Y_1$ . At time 2, the state of the system is described by two variables:  $X_1$ , giving the quantity of remaining supply (now considered known); and  $X_2$ , giving the quantity of crop expected from the planting (mean value at time 2). During period 2, only one decision is made. This decision, denoted  $y$ , depends on both  $X_1$  and  $X_2$ , and is the consumption for the period. As with other decisions, it is made so as to maximize the discounted mean present value of consumer

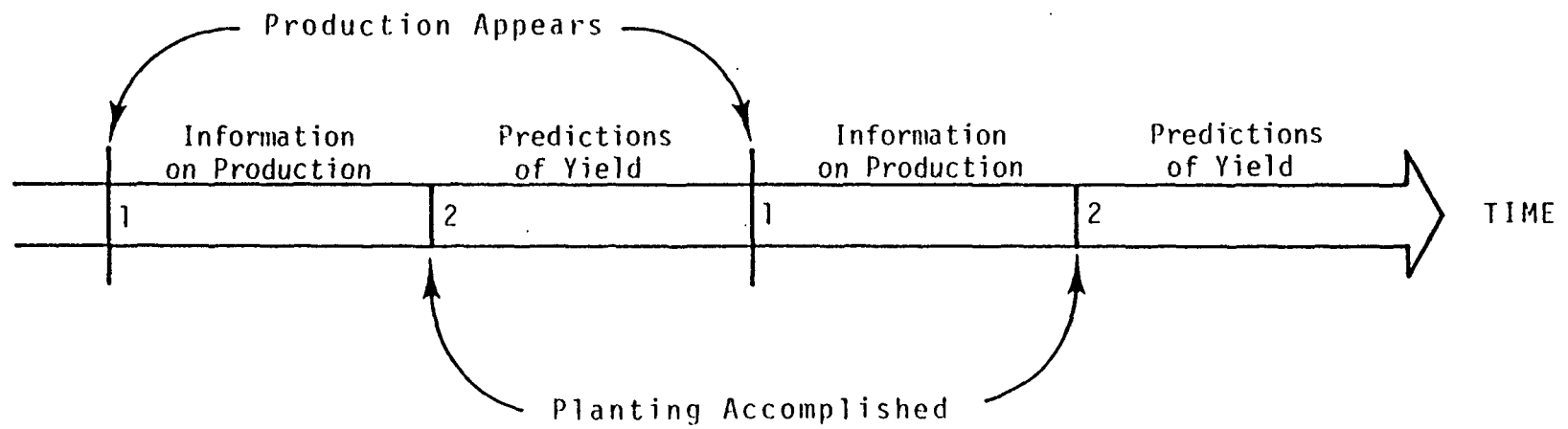


Figure 3.1 Timing Assumptions

gains plus producer gains from the present indefinitely into the future. As time advances from time 2 of the current year to time 1 of the following year, information is obtained on the yield of the planted crop, leading to a supply estimate that may differ from the one made at planting. The consumption of the quantity  $y$  also takes place during this period. The events outlined above are described mathematically by state variables and state transformations. The state variables are  $x$  (at time 1) and  $X_1, X_2$  (at time 2). The period 1 state transformation is given by

$$X_1 = x - Y_1 + \phi_1$$

$$X_2 = Y_2.$$

Here  $\phi_1$  represents the new information obtained during period 1, resolving the uncertainty in the crop on hand. The period 2 state transformation is given by

$$x = X_1 + X_2 - y + \phi_2,$$

where  $\phi_2$  represents the new information obtained during period 2, revising the estimate of the crop about to be harvested. Both  $\phi_1$  and  $\phi_2$  are random variables with 0 mean.

Figure 3.2 shows these structural variables located on a time line.

To complete the specification of the structure of the model, we introduce incremental value functions and cumulative value functions.

The incremental value function for each period accounts for consumer and producer gains during that period. The domain of the first period incremental value function is the decision space of coordinates  $Y_1, Y_2$ . For each possible pair,  $Y_1, Y_2$ , the function assigns the gross value

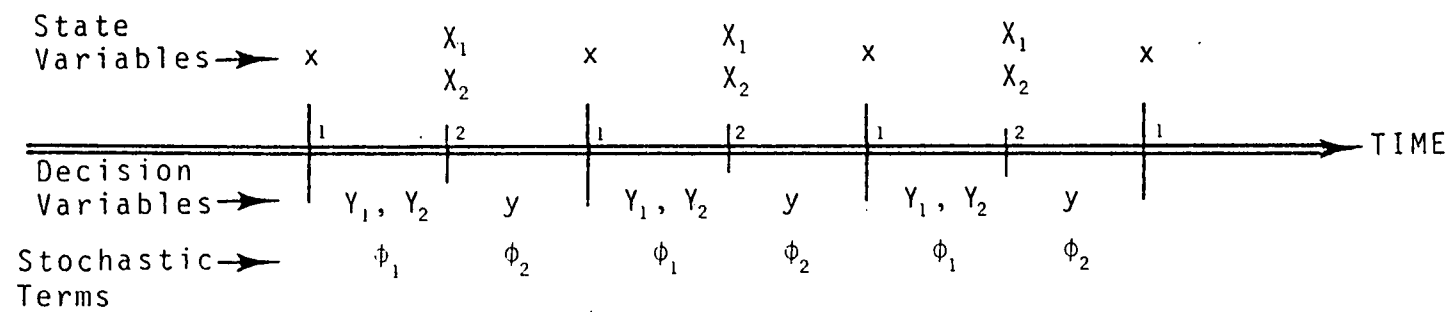


Figure 3.2 Structural Variables



(welfare) associated with consumption  $Y_1$  minus the cost associated with planting  $Y_2$ . The welfare\* and cost functions are approximated by second degree polynomial as follows:

$$\text{Welfare} = a_1 Y_1^2 + b_1 Y_1;$$

$$\text{Cost} = -a_2 Y_2^2 - b_2 Y_2.$$

The first period incremental value function  $F$  is thus given by

$$F(Y_1, Y_2) = a_1 Y_1^2 + b_1 Y_1 + a_2 Y_2^2 + b_2 Y_2.$$

In the second period, there is no production cost, so the incremental value function  $F$  is based on the welfare term alone, and is given by

$$F(y) = a_1 y^2 + b_1 y.$$

Notice that this function is defined on the one-dimensional decision plane of second period consumption.

The cumulative value function at each time is defined on the state space at that time, rather than the decision space. It is the function which is maximized in the decision process. At time 1, the state space is one dimensional. For a given state value  $x$ , the value  $v(x)$  taken by the time 1 value function  $v$  is the mean value of the sum of discounted terms  $F(Y_1, Y_2)$  and  $f(y)$  of all future years, where the decisions  $y$ ,  $Y_1$ , and  $Y_2$  are always made optimally, conditional on the starting stock estimate  $x$ . At time 2, the state space is two dimensional. For given state values  $X_1, X_2$ , the value  $V(X_1, X_2)$  taken by the period 2 value function  $V$  is the mean value of

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\* In the sense of gains to society, as used in the economic literature.

the sum of discounted terms  $F(Y_1, Y_2)$  and  $F(y)$ , with decisions made optimally, conditional on the supply estimates  $X_1$  (current) and  $X_2$  (growing).

In our model, the cumulative value functions  $v$  and  $V$  are approximated by second degree polynomials as follows:

$$\begin{aligned} v(x) &= qx^2 + \ell x + k, \\ V(X_1, X_2) &= Q_{11}X_1^2 + 2Q_{12}X_1X_2 + Q_{22}X_2^2 \\ &\quad + L_1X_1 + L_2X_2 + K. \end{aligned}$$

The "solution" of our model consists of the determination of the value functions  $v$  and  $V$  by finding their coefficients  $q$ ,  $\ell$ ,  $k$ ,  $Q_{ij}$ ,  $L_i$  and  $K$ . Simultaneously with this solution, we find the decision rules, or the functions which assign optimal consumption and planting decisions to the various possible values of the state variables.

Given these decision rules, we can also calculate other functions of economic interest, such as the components of the incremental and cumulative value functions which accrue to consumers and to suppliers. The consumers gain for period 1 is

$$a_1Y_1^2 + b_1Y_1 - (2a_1Y_1 + b_1)Y_1 = -a_1Y_1^2$$

since the price is the marginal welfare at consumption level  $Y_1$ , or  $2a_1Y_1 + b_1$ . The suppliers gain for period 1 is

$$(2a_1Y_1 + b_1)Y_1 + a_2Y_2^2 + b_2Y_2,$$

since the suppliers receive payment for period 1 consumption  $Y_1$  while spending production costs for period 1 planting  $Y_2$ . In period 2, the consumers surplus is

$$a_1 y^2 + b_1 y - (2a_1 y + b_1)y = -a_1 y^2$$

and the suppliers gain is

$$(2a_1 y + b_1)y.$$

Cumulative value functions are obtained as the mean discounted sum of these incremental value functions. We use quadratic approximations just as for the total value functions. Thus, for the suppliers cumulative value functions  $w$ ,  $W$  we have

$$\begin{aligned} w(x) &= s x^2 + t x + u, \\ W(X_1, X_2) &= S_{11} X_1^2 + 2S_{12} X_1 X_2 + S_{22} X_2^2 \\ &\quad + T_1 X_1 + T_2 X_2 + U, \end{aligned}$$

and for the consumers cumulative value function  $z$ ,  $Z$  we have the differences

$$z = v - w,$$

$$Z = V - W.$$

Each of the value functions discussed above is specified in Table 3.1.

### 3.2 Dynamic Programming

A functional equation known as the optimality principle of dynamic programming provides the means for calculating the value functions and decision rules discussed above. The optimality principle can be stated:

"An optimal policy has the property that whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision." [12]

Table 3.1 Value Functions for Two Period Model			
	Suppliers	Consumers	Total
Time 1 Cumulative	$w(x) = sx^2 + tx + u$	$z = v - w$	$v(x) = qx^2 + lx + k$
Period 1 Incremental	$(2a_1y_1 + b_1)y_1 + a_2y_2^2 + b_2y_2$	$- a_1y_1^2$	$F(y_1, y_2) = a_1y_1^2 + b_1y_1 + a_2y_2^2 + b_2y_2$
Time 2 Cumulative*	$W(X) = X'SX + T'X + U$	$Z = V - W$	$V(X) = X'QX + L'X + K$
Period 2 Incremental	$(2a_1y + b_1)y$	$- a_1y^2$	$a_1y^2 + b_1y$
*Matrix notation used in this line, $X = (X_i)$ , $S = (S_{ij})$ , $T = (T_i)$ , $Q = (Q_{ij})$ , $L = (L_i)$ .			

Applying this for period 1, we have for each  $x$ ,

$$v(x) = \max_{Y_1, Y_2} [F(Y_1, Y_2) + \overline{\rho V(x - Y_1 + \phi_1, Y_2)}] \quad (3.1)$$

The maximization is subject to the constraints

$$0 \leq Y_1 \leq x, Y_2 \geq 0.$$

The bar over the second term in the brackets indicates the mean value with respect to the random variable  $\phi_1$ . For period 2, the optimality principle is

$$V(X_1, X_2) = \max_{0 \leq y \leq X_1} [F(y) + \overline{\rho v(X_1 + X_2 - y + \phi_2)}]. \quad (3.2)$$

Here the bar indicates the mean value with respect to the random variable  $\phi_2$ .

Given the coefficients  $q, \ell, k$ , of the function  $v$ , and a pair of values  $X_1, X_2$  of the state variables, it is easy to find  $V(X_1, X_2)$  from Equation 3.2. This is, in fact, a very trivial quadratic programming problem. Similarly, if we are given the coefficients  $Q_{ij}, L_i, K$  of  $V$ , and a value  $x$  of the state variable, we find  $v(x)$  by solving a slightly more complex quadratic programming problem (Equation 3.1). Assume now that we have an approximation of the coefficients of  $v$ . To determine the coefficients of  $V$ , we first evaluate  $V$  (by quadratic programming) on a selected set of points in the state space. Then, we find the second degree polynomial in  $X_1$  and  $X_2$  which gives the least squares fit to  $V$  at the selected points.  $V$  is then approximated by that second degree polynomial. A similar procedure can then be used to obtain a new approximation of  $v$ . Repeating the procedure of going from an

estimate of  $v$  to an estimate of  $V$  and then to a new estimate of  $v$ , we obtain a convergent sequence of functions. The limiting values are taken as the simultaneous solution of Equations 3.1 and 3.2.

Since our central interest is in the value of information, we look now at the way the model responds to changes in information quality. Information quality is represented by the random variables  $\phi_1$  and  $\phi_2$  occurring in the state transformations. The more variability is present in  $\phi_1$ , the poorer the information on the new crop at harvest time. The more variability is present in  $\phi_2$ , the poorer the correspondence between the intended production at planting time and the estimated production at harvest time.

Because of our use of quadratic value functions and the fact that  $\phi_1$  and  $\phi_2$  have zero means, we can represent  $\phi_1$  and  $\phi_2$  by their second moments only,  $\sigma_1^2$  and  $\sigma_2^2$ . This is clear on expansion of the terms containing  $\phi_1$  and  $\phi_2$  in Equations 3.1 and 3.2. Thus, Equation 3.1 becomes

$$\begin{aligned} v(x) = \max_{Y_1, Y_2} [ & F(Y_1, Y_2) + \rho(Q_{11}(x - Y_1 + \phi_1)^2 \\ & + 2Q_{12}(x - Y_1)Y_2 + Q_{22}Y_2^2 \\ & + L_1(x - Y_1) + L_2Y_2 + K) ]. \end{aligned} \quad (3.3)$$

Expanding the term involving  $\phi_1$ , we obtain

$$(x - Y_1 + \phi_1)^2 = (x - Y_1)^2 + \sigma_1^2.$$

Writing  $Y_1^*$  and  $Y_2^*$  for the maximizing values of  $Y_1$  and  $Y_2$  in Equation 3.3 we obtain

$$\begin{aligned}
 v(x) = & F(Y_1^*, Y_2^*) + \rho(Q_{11}(x - Y_1^*)^2 + Q_{11}\sigma_1^2 \\
 & + 2Q_{12}(x - Y_1^*)Y_2^* + Q_{22}Y_2^{*2} + L_1(x - Y_1^*) \\
 & + L_2Y_2^* + K) .
 \end{aligned} \tag{3.4}$$

It is important to notice that  $Y_1^*$  and  $Y_2^*$  do not depend on  $K$  or  $\sigma_1^2$ , though of course they do depend on  $x$ ,  $Q_{ij}$ , and  $L_1$ .

We now expand Equation 3.2 in similar fashion to show the dependence of  $V(X_1, X_2)$  on  $\sigma_2^2$ .

$$\begin{aligned}
 V(X_1, X_2) = & \max_{0 \leq y \leq X_1} [f(y) + \rho(q(X_1 + X_2 - y)^2 \\
 & + q\sigma_2^2 + \ell(X_1 + X_2 - y) + k)] .
 \end{aligned}$$

If  $y^*$  is the maximizer, we can write

$$\begin{aligned}
 V(X_1, X_2) = & f(y^*) + \rho(q(X_1 + X_2 - y^*)^2 \\
 & + \ell(X_1 + X_2 - y^*) + k + q\sigma_2^2) .
 \end{aligned} \tag{3.5}$$

Here we observe that  $y^*$  does not depend on  $k$  or  $\sigma_2^2$ , though it does depend on  $X_1$ ,  $X_2$ ,  $q$  and  $\ell$ . Now we are in a position to calculate the dependence of  $v(w)$  on  $\sigma_1^2$  and  $\sigma_2^2$ . Differentiating Equation 3.4 with respect to  $\sigma_1^2$  and  $\sigma_2^2$ ,

$$dv(x) = dk = \rho Q_{11} d\sigma_1^2 + \rho dK. \tag{3.6}$$

But  $K$  is the constant term in the expansion of  $V(X_1, X_2)$  in  $X_1$  and  $X_2$ . It consists of terms independent of  $\sigma_1^2$  and  $\sigma_2^2$ , and the term (from Equation 3.5)

$$\rho(k + q\sigma_2^2).$$

Thus,

$$dK = \rho(dk + qd\sigma_2^2).$$

Combining this with Equation 3.6,

$$\begin{aligned} dk &= \rho Q_{11} d\sigma_1^2 + \rho^2 (dk + qd\sigma_2^2) \\ (1 - \rho^2) dk &= \rho Q_{11} d\sigma_1^2 + \rho^2 q d\sigma_2^2. \end{aligned}$$

Thus, we have

$$dv(x) = \frac{\rho}{1-\rho^2} [Q_{11} d\sigma_1^2 + \rho q d\sigma_2^2]. \quad (3.7)$$

The total cumulative value function at time 1 varies with changes in information quality according to Equation 3.7. Notice that we don't need to find  $K$  or  $k$  to use this expression, but only  $Q_{11}$  and  $q$ . This is fortunate, because the numerical procedure described above for solving the dynamic programming equations provides speedy convergence in  $Q_{ij}$  and  $q$ , but very slow convergence in  $K$  and  $k$ .

By an argument similar to the above, we can see that the differentials of the suppliers cumulative value function with respect to  $\sigma_1^2$  and  $\sigma_2^2$  is given by

$$dw(x) = \frac{\rho}{1-\rho^2} [S_{11} d\sigma_1^2 + \rho s d\sigma_2^2], \quad (3.8)$$



and of course, for the consumers,

$$dz(x) = dv(x) - dw(x) \quad (3.9)$$

$$= \frac{\rho}{1-\rho^2} [(Q_{11} - S_{11})d\sigma_1^2 + \rho(q - s)d\sigma_2^2] .$$

Other quantities of the model than the value of information are also of interest. These include the means and standard deviations over time of the consumption rates, annual production, stock carryover and price. These are not easy to obtain analytically from the value function coefficients, but they are easily estimated by Monte Carlo simulation, making use of the decision rule determined by the dynamic programming procedure. The simulation proceeds as follows. A starting state value,  $x$ , is chosen. The maximization indicated in Equation 3.1 is performed, just as in an iteration of the dynamic programming procedure. But this time the value function  $V$  is already known, rather than being one of a sequence of estimates. The quantity  $v(x)$  is not needed now, but only the maximizer  $(Y_1^*, Y_2^*)$ . A random sample  $\phi_1^*$  of the probability distribution of  $\phi_1$  is taken. The period 1 state transformation is then applied with the values  $Y_1^*$ ,  $Y_2^*$ , and  $\phi_1^*$ , giving the time 2 state values  $X_1$  and  $X_2$ , thus:

$$X_1 = x - Y_1^* + \phi_1^*,$$

$$X_2 = Y_2^*.$$

In the same way, the maximizer  $y^*$  appropriate for the state values  $X_1$  and  $X_2$  is calculated from Equation 3.2, after which the  $\phi_2$  distribution is sampled and the period 2 state transformation is applied. This produces a new time 1 state value  $x$ , and the entire procedure is repeated. Means and standard deviations of the variables involved are easily obtained.

### 3.3 Selection of State Points

The values of each state variable selected to form the grid for value function approximation are based on a specified mean and standard deviation. Since the grid consists of uniformly spaced points, we can derive a simple formula for their location based on the number of points  $n$ , the mean  $\mu$ , and the standard deviation  $\sigma$ .

Let  $\delta$  be the interval between points. If  $n$  is odd, the deviations from  $\mu$  are

$$0, \pm \delta, \pm 2\delta, \dots, \pm \left(\frac{n-1}{2}\right)\delta.$$

Thus the standard deviation is

$$\begin{aligned}\sigma &= \sqrt{\frac{2[\delta^2 + (2\delta)^2 + \dots + \left(\frac{(n-1)\delta}{2}\right)^2]}{n}} \\ &= \sqrt{\frac{2\delta^2}{n} [1 + 2^2 + 3^2 + \dots + \left(\frac{n-1}{2}\right)^2]} ,\end{aligned}$$

Since  $\sum_{j=1}^k j^2 = \frac{k(k+1)(2k+1)}{6}$ , this becomes

$$\begin{aligned}\sigma &= \delta \sqrt{\frac{\frac{2}{n} \cdot \frac{(n-1)(n+1)}{2} \cdot \frac{n}{6}}{12}} \\ &= \delta \sqrt{\frac{n^2-1}{12}} .\end{aligned}$$

Thus, the interval is given by

$$\delta = \sigma \sqrt{\frac{12}{n^2-1}},$$

and for  $j = 1, \dots, n$ , the grid values of the state variable are

$$\mu + \sigma \sqrt{\frac{12}{n^2-1}} \left(j - \frac{n+1}{2}\right).$$

This deviation was based on odd  $n$ , but it is easy to verify that the same formula holds for even  $n$ .

Logically,  $\mu$  and  $\delta$  should be consistent with the mean and standard deviation of the state variable in question as obtained from the simulation described above. Since  $\mu$  and  $\delta$  are required before the dynamic programming equations are solved, however, this consistency cannot be guaranteed in advance. But an iterative trial and error procedure has been found satisfactory.

### 3.4 Details on One-Stage Optimization

The optimizations indicated in Equations 3.1 and 3.2 are linearly constrained maximizations of quadratic forms. In this section we put them into standard quadratic programming form and outline solution algorithms.

For the period 2 maximization, the basic equation is

$$V(X_1, X_2) = \max_{0 \leq y \leq X_1} [f(y) + \rho v(X_1 + X_2 - y + \phi_2)].$$

Putting in the expansions of  $f$  and  $v$ , this becomes

$$V(X_1, X_2) = \max_{0 \leq y \leq X_1} \left\{ a_1 y^2 + b_1 y + \rho [q(X_1 + X_2 - y + \phi_2)^2 + 2(X_1 + X_2 - y) + k] \right\},$$

where we have used the fact that  $\bar{\phi}_2 = 0$ . Reordering in terms of powers of  $y$ , this becomes

$$V(X_1, X_2) = \max_{0 \leq y \leq X_1} \left\{ (a_1 + \rho q)y^2 + [b_1 - 2\rho q(X_1 + X_2) - \rho \ell]y + \rho[q(X_1 + X_2)^2 + \ell(X_1 + X_2) + k + q\sigma_2^2] \right\}.$$

Let

$$A = a_1 + \rho q,$$

$$B = b_1 - 2\rho q(X_1 + X_2) - \rho \ell,$$

$$C = \rho[q(X_1 + X_2)^2 + \ell(X_1 + X_2) + k + q\sigma_2^2].$$

Now the maximization is in the standard quadratic programming form.

Maximize

$$Ay^2 + By + C$$

Subject to:

$$y \geq 0;$$

$$y \leq X_1.$$

With the data of our problem,  $A$  is always negative, so the objective function is concave, and its maximum may occur at an interior point on the interval  $[0, X_1]$ . To solve the problem, we first find the unconstrained maximizer of  $Ay^2 + By + C$ , which is

$$y = -\frac{B}{2A},$$

and then check whether it meets the constraints. Thus, the true maximizer  $y^*$  is given by

$$y^* = \min[X_1, \max(0, -\frac{B}{2A})],$$

and the maximum is given by

$$V(X_1, X_2) = Ay^{*2} + By^* + C.$$

For the period 1 optimization, the basic equation is

$$v(x) = \max_{Y_1, Y_2} [F(Y_1, Y_2) + \rho \overline{V(x - Y_1 + \phi_1, Y_2)}].$$

Putting in the expansions of  $F$  and  $V$ , this becomes

$$\begin{aligned} v(x) = \max_{Y_1, Y_2} \bigg\{ & a_1 Y_1^2 + b_1 Y_1 + a_2 Y_2^2 + b_2 Y_2 \\ & + \rho [Q_{11} (x - Y_1 + \phi_1)^2 + 2Q_{12} (x - Y_1) Y_2 \\ & + Q_{22} Y_2^2 + L_1 (x - Y_1) + L_2 Y_2 + K] \bigg\} \end{aligned}$$

Collecting in terms of powers of  $Y_1$  and  $Y_2$ , we obtain

$$\begin{aligned} v(x) = \max_{Y_1, Y_2} [ & E_{11} Y_1^2 + 2E_{12} Y_1 Y_2 + E_{22} Y_2^2 \\ & + F_1 Y_1 + F_2 Y_2 + G], \end{aligned}$$

where

$$E_{11} = A_{11} + \rho Q_{11},$$

$$E_{12} = -\rho Q_{12},$$

$$E_{22} = A_{22} + \rho Q_{22},$$

$$F_1 = B_1 - 2\rho Q_{11}x - \rho L_1,$$

$$F_2 = B_2 + 2\rho Q_{12}x + \rho L_2,$$

$$G = \rho[Q_{11}x^2 + L_1x + K + Q_{11}\sigma_2^2].$$

The constraints in this case are:

$$Y_1, Y_2 \geq 0;$$

$$Y_1 \leq x;$$

Figure 3.3 shows the structure of this quadratic programming problem. A possible set of level lines for the objective function is included, with the unconstrained and the true maximizer. The problem can be solved by a simple search procedure. First, one finds the unconstrained maximizer, by the formula (in matrix notation)

$$\tilde{Y} = -1/2E^{-1}F.$$

If this satisfies the constraints, the maximum is given by

$$v(x) = \tilde{Y}'EY + \tilde{Y}'F + G.$$

If not, one finds the maximum of the objective function on the three line segments

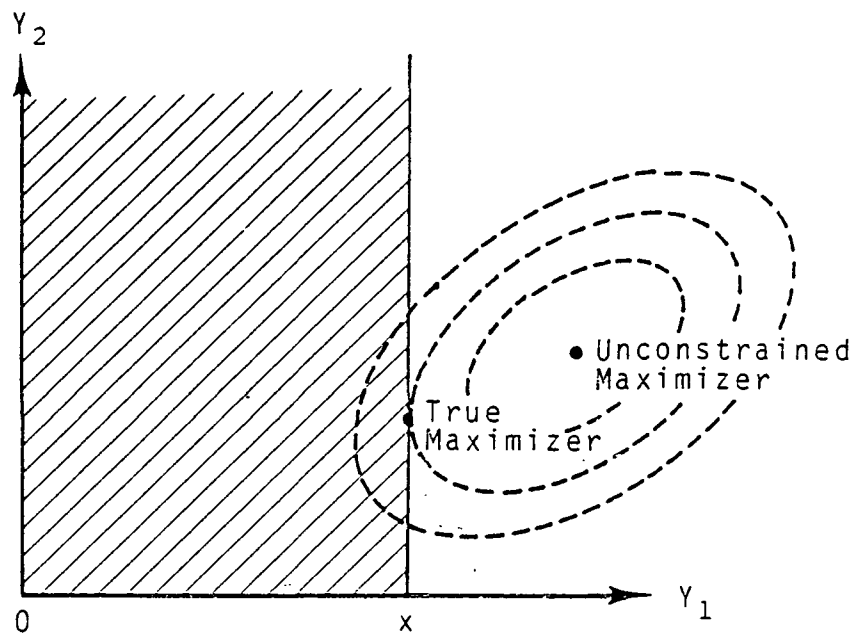


Figure 3.3 Structure of Period 1 Quadratic Programming Problem

$$(1) \quad 0 \leq Y_1 < x, Y_2 = 0,$$

$$(2) \quad 0 \leq Y_2, Y_1 = 0,$$

$$(3) \quad 0 \leq Y_2, Y_1 = x.$$

The global maximum is then the largest of these three maxima.

We illustrate the calculation of these constrained maxima by doing case (1). The others are similar. For this case, we substitute  $Y_2 = 0$  in the objective function, obtaining

$$\max_{0 \leq Y_1 \leq x} [E_{11} Y_1^2 + F_1 Y_1 + G].$$

The maximizer is

$$Y_1^* = \min\left[x, \max\left(0, -\frac{F_1}{2E_{11}}\right)\right],$$

and the maximum is

$$E_{11} Y_1^{*2} + F_1 Y_1^* + G.$$

### 3.5 Data Requirements of Model

The input data required for calculations with the one-country two-period version of the production and distribution model are simply the coefficients  $(a_1, a_2, b_1, b_2)$  of the incremental value functions  $f$  and  $F$ , the discount factor  $\rho$  and the variances  $\sigma_1^2$  and  $\sigma_2^2$  describing information quality.



The value function coefficients are to be obtained econometrically. Since the results of demand and production function estimation are usually quoted in the dimensionless form of elasticities, we indicate here how the coefficients can be obtained from demand and production elasticity estimates together with mean prices and quantities.

Assume that on the average, annual production equals annual consumption, so that there is no trend in carryover stocks. Let this annual quantity be denoted  $\Pi$ , and let the average price observed at this consumption rate be  $P$ . Let the price elasticity of demand be  $\varepsilon$  and the cost elasticity of production be  $\eta$ . The consumption during one period should average

$$\Gamma = 1/2\Pi.$$

The price, or marginal value of consumption, in a single period can be written

$$f'(\Gamma) = 2a_1\Gamma + b_1,$$

so that the rate of change of  $\Gamma$  with respect to the price  $f'(\Gamma)$  is  $\frac{1}{2a_1}$ . By definition of price elasticity, we have

$$\varepsilon = \frac{P}{1/2\Pi} \cdot \frac{1}{2a_1} = \frac{P}{\Pi a_1},$$

from which

$$a_1 = \frac{P}{\varepsilon\Pi}.$$

Putting this in the price equation, we obtain

$$p = \frac{2P}{\varepsilon\Pi} \left(\frac{1}{2}\Pi\right) + b_1 ,$$

from which

$$b_1 = P\left(1 - \frac{1}{\varepsilon}\right) .$$

The coefficients  $a_2$  and  $b_2$  can be obtained similarly. The equilibrium price is (on the average)

$$2a_2\Pi + b_2 ,$$

so that the cost elasticity of production is written

$$\eta = \frac{P}{\Pi} \cdot \frac{1}{2a_2} ,$$

from which

$$a_2 = \frac{P}{2\Pi\eta} ,$$

and

$$b_2 = P\left(1 - \frac{1}{\eta}\right) .$$

Discount rates are usually quoted annually. If  $r$  is the annual discount rate, the discount factor  $\rho$  for one six-months period is just

$$\left(\frac{1}{1+r}\right)^{\frac{1}{2}} .$$

Finally, information quality is usually quoted in terms of the accuracy of production estimates at specified times. Suppose the standard deviation

of the error of the production estimate at harvest (time 1) is the fraction  $\alpha_1$  of the average production  $\Pi$ . Then

$$\sigma_1^2 = (\alpha_1 \Pi)^2 .$$

If the standard deviation of the error of the production estimate at planting is the fraction  $\alpha_2$  of  $\Pi$ , then

$$(\alpha_2 \Pi)^2 = \sigma_1^2 + \sigma_2^2 ,$$

so that

$$\sigma_2^2 = (\alpha_2^2 - \alpha_1^2) \Pi^2 .$$

### 3.6 Illustrative Example--Simplified Model

To illustrate the use of the model described above, we consider the production and temporal distribution of wheat, treating the entire world as a unit. We will estimate the benefits to consumers and suppliers of specified information improvements, but with this simplified model we cannot distinguish United States benefits from those accruing to other regions.

The base case data for this illustration, elasticities, prices, quantities and accuracies, are given in Table 3.2. As discussed in Section 3.5 on the data requirements of the model, these parameters are used to calculate the coefficients ( $a_1$ ,  $a_2$ ,  $b_1$ ,  $b_2$ ) of the incremental value functions, the discount factor  $\rho$  and the variances  $\sigma_1^2$  and  $\sigma_2^2$ . These calculated data are given in Table 3.3.

Table 3.2 Input Data for Production and Distribution of Wheat

Description	Symbol	Value
Price Elasticity of Demand	$\epsilon$	-0.2
Cost Elasticity of Production	$\eta$	0.5
Sample Wheat Price	$\rho$	\$140/metric ton
Sample Annual Production	$\pi$	350 million tons
Annual Discount Rate	$r$	0.06
Fractional Standard Error of Production Estimate		
—At Harvest	$\alpha_1$	0.08
—At Planting	$\alpha_2$	0.12

Table 3.3 Value Function Coefficients  
and other Parameters

Symbol	Value
$a_1$	-2
$a_2$	-0.4
$b_1$	840
$b_2$	140
$\rho$	0.971
$\sigma_1^2$	784
$\sigma_2^2$	980

To begin the dynamic programming calculations, we must specify an initial choice of grid points in the state space for each time. Our initial choice of the grid parameters (means and standard deviations) is given in Table 3.4. The actual grids are based on a discrete uniform distribution of 5 points in each dimension. Thus, a rectangular grid of 25 points is used at time 2, and a linear grid of 5 points is used at time 1.

The dynamic programming calculation now leads to the results:

$$Q = \begin{pmatrix} -.655 & -.262 \\ -.262 & -.376 \end{pmatrix}, \quad L = \begin{pmatrix} 594 \\ 505 \end{pmatrix},$$

$$S = \begin{pmatrix} 2.746 & .635 \\ .635 & 1.141 \end{pmatrix}, \quad T = \begin{pmatrix} -1181 \\ -614 \end{pmatrix},$$

$$q = -.432, \quad \ell = 469,$$

$$s = 1.248, \quad t = 852.$$

Using these coefficients in the decision rule, a 50-year simulation produces information such as the means and standard deviations of the state and decision variables, prices, costs, etc. Of particular interest at this stage are the moments of the state variables  $x$ ,  $X_1$ , and  $X_2$ , since these are to be compared with their assumed values used in setting up the grids. Thus, the simulated mean and standard deviations of  $x$ ,  $X_1$  and  $X_2$  are given in Table 3.4, together with the prior assumptions.

The whole calculation is now reiterated, using new values of the grid parameters. It has been found that stable and rapid convergence is obtained

Table 3.4 Initial Assumptions on Grids In State Space and Output of Simulation

State Variable	Mean (metric tons)		Standard Deviation (metric tons)	
	Assumed	Simulated	Assumed	Simulated
x (Time 1 Supply)	367.6	391.3	25.0	38.8
$X_1$ (Time 2 Supply)	190.7	217.2	37.9	43.1
$X_2$ (Time 2 Planted)	341.6	340.8	9.9	10.1

if the new mean values of  $x$ ,  $X_1$  and  $X_2$  are taken as the midpoints of the original and simulated values, and similarly with the standard deviations. Table 3.5 records the output of the simulation runs through ten iterations. At this point, the grid has stabilized, so convergence is achieved. The final values of the value function coefficients are as follows:

$$\begin{aligned}
 a &= \begin{pmatrix} -.205 & -.128 \\ -.128 & -.143 \end{pmatrix}, & L &= \begin{pmatrix} 318 \\ 290 \end{pmatrix}, \\
 S &= \begin{pmatrix} 1.961 & 1.065 \\ 1.065 & 1.170 \end{pmatrix}, & T &= \begin{pmatrix} -794 \\ -406 \end{pmatrix}, \\
 q &= -.157, & \lambda &= 261, \\
 s &= 1.222, & t &= -450.
 \end{aligned}$$

These enable us to calculate the value of specified information improvements according to Equations 3.7, 3.8 and 3.9 of Section 3.2.

Suppose the improved information provides a reduction of the fractional standard error at harvest (time 1) from .08 to .06, while the fractional standard error at planting (time 2) remains .12. Then the error variances and the state transformation variances  $\sigma_1^2$  are as shown in Table 3.6, Case 2.

Since the changes in  $\sigma_1^2$  in going from Case 2 to Case 1 are

$$d\sigma_1^2 = -343, \quad d\sigma_2^2 = 343,$$

the total present value benefit, from Equation 3.7 is



Table 3.5 Convergence of Grid Parameters						
Iteration	Means			Standard Deviations		
	x	$X_1$	$X_2$	x	$X_1$	$X_2$
1	397.33	223.95	339.91	41.43	47.46	10.97
2	399.03	225.93	339.24	43.43	50.41	10.55
3	399.78	226.78	338.91	44.29	51.66	10.15
4	400.27	227.35	338.73	44.67	52.19	9.94
5	401.04	228.11	338.81	44.91	52.50	9.86
6	400.93	228.04	338.67	45.03	52.68	9.76
7	401.37	228.47	338.75	45.12	52.79	9.74
8	401.11	228.25	338.62	45.14	52.84	9.70
9	401.56	228.66	338.77	45.19	52.88	9.70
10	400.99	228.14	338.55	45.17	52.88	9.65

Table 3.6 Benefits of Improved Information									
Case	Fractional Std. Error of Estimate		Variance of Error Estimate		$\sigma_1^2$	$\sigma_2^2$	Benefit, \$ million/year		
	Time 1	Time 2	Time 1	Time 2			Suppliers	Consumers	Total
1 (Base)	.08	.12	784	1764	784	980	-----	-----	---
2	.06	.12	441	1764	441	1323	-273	291	18
3	.04	.12	196	1764	196	1568	-467	499	32
4	.06	.08	441	784	441	343	-1471	1643	172

$$\frac{.971}{1-(.971)^2} [(-.205)(-343) + .971(-.157)(343)]$$

$$= 306.2 .$$

We annualize this by multiplication by the annual discount rate .06, so the annual total benefit is \$18 million. Similarly, we calculate annual benefits to consumers of \$291 million and an annual disbenefit to suppliers of \$273 million. Table 3.6 presents these figures, as well as the benefits corresponding to two other cases of improved information. If the reduction of fractional standard error at harvest is from .08 to .04, while the prediction at planting time still has fractional standard error .12, then the total benefit is increased substantially to \$32 million per year. Finally, we consider a different kind of information improvement, an improved ability to predict production at planting time. This could perhaps be achieved through better understanding of weather patterns, development of hardier varieties of wheat, or other methods that go beyond measurements centered in the growing crop itself. Assuming a reduction of fractional standard error from .12 to .08 at planting time, with a reduction from .08 to .06 at harvest time, the total benefit comes out to \$172 million per year. Notice that the potential benefit of reduction in the variability of the system of crop production is far greater than the benefit of information limited to earlier knowledge of production without reduced variability.

All of the benefits calculated are perhaps surprisingly low, in view of the economic importance of wheat worldwide. But it should be remembered that there are no trade effects included in the model. We are treating only aggregate production decisions and temporal distribution, assuming in effect

that the allocation of production among regions is always optimal,\* and that the distribution of the harvested crop among regions is likewise optimal.

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\*As if based on perfect information.

#### 4. TWO-REGION PRODUCTION AND DISTRIBUTION MODEL

The model presented here is a straightforward extension of the simplified model discussed above. The year is divided into  $m$  periods (six in our numerical illustrations) and export decisions are made simultaneously with consumption versus storage decisions at the beginning of each period.

Two regions are considered, called the exporting unit and the importing unit. In each region, planting decisions are made at specific times of year, depending on the crop under study. For wheat, spring and winter sowing are distinguished, and the southern hemisphere sowing occurs half a year out of phase with northern hemisphere winter sowing.

##### 4.1 State Variables

At time 1, the beginning of the first period, there are two state variables. The first,  $x_1$ , refers to the mean value at time 1 of stocks in the exporting unit, including the newly available production (still uncertain) and the carryover from the previous crop year (known). The second state variable refers to the mean value at time 1 of stocks in the importing unit. We model production as if the annual harvest were instantaneous, taking place at time 1. This procedure presents no difficulties as long as we choose time 1 appropriately within the crop cycle. From time 1 until the start of the period after the first planting, the same two state variables are used to track the state of the system. At each time during this interval,  $x_1$  refers to the mean value of remaining supply in the exporting unit, after accumulated consumption and accumulated exports;  $x_2$  refers to the mean value of remaining supply in the importing unit, including imports and after accumulated consumption. When the first planting occurs in either unit, an

additional state variable is created to represent the mean value of the production expected to result from the planting in the following crop year.

Thus, there may be three or four state variables in the middle periods of the crop year, and there will be four state variables by the end of the crop year. When planting has occurred in the exporting unit, the new state variable is denoted  $x_2$ . When planting has occurred in the importing unit, the new state variable is denoted  $x_4$ .

#### 4.2 Decision Variables

The vector of decision variables, like the state vector, has fluctuating dimension. There are always at least three decision variables. They are:  $y_1$ , consumption in the exporting unit;  $y_2$ , exports; and  $y_4$ , consumption in the importing unit. In the planting periods for the exporting unit, there is also the intended production  $y_3$ , and in the planting periods for the importing unit, there is the intended production,  $y_5$ .

#### 4.3 State Transformation

The state vector undergoes a change from one time to the next as a result of decisions and new information on existing or potential (planted) supply. The vector  $\phi$  is used to represent new information. Its elements are random variables of zero mean. Using subscripts to indicate time, we can write the state transformation in vector form as

$$X_{t+1} = M_t X_t + N_t Y_t + \phi_t. \quad (4.1)$$

The structure of  $M_t$ ,  $N_t$ , and  $\phi_t$ , depend on the planting schedule for the particular crop. In the case of wheat, we will model planting as occurring in periods 2 and 5 in the exporting unit (United States), and in periods 2, 5 and 6 in the importing unit (rest of the world). For this case, there

are six periods, and the year begins June 1. The state transformation matrices are as given in Table 4.1.

#### 4.4 Value Functions

As in the one-region model, we are fundamentally concerned with a cumulative value function, the maximization of which is assumed to govern all decision making. This cumulative value function is the discounted sum of incremental value functions accounting for consumer and producer gains and transportation costs, period by period. Since interest is the only significant component of storage costs [10], these costs are not explicitly accounted for in the incremental value functions, but are implicitly accounted for by discounting in the formation of the cumulative value function.

The gross value associated with one period's consumption  $y_1$  in the exporting unit is approximated by the polynomial

$$\alpha_1 y_1^2 + \beta_1 y_1,$$

and the gross value associated with one period's consumption  $y_4$  in the importing unit is approximated by

$$\alpha_2 y_4^2 + \beta_2 y_4.$$

These are consistent with linear demand functions

$$\text{price} = 2\alpha_1 y_1 + \beta_1$$

and

$$\text{price} = 2\alpha_2 y_4 + \beta_2$$

Table 4.1 State Transformation Matrices for  
Wheat Production and Distribution

Period	M	N
1	$\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$	$\begin{pmatrix} -1 & -1 & 0 \\ 0 & 1 & -1 \end{pmatrix}$
2	$\begin{pmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \\ 0 & 0 \end{pmatrix}$	$\begin{pmatrix} -1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$
3	$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$	$\begin{pmatrix} -1 & -1 & 0 \\ 0 & 0 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 0 \end{pmatrix}$
4	$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$	$\begin{pmatrix} -1 & -1 & 0 \\ 0 & 0 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 0 \end{pmatrix}$
5	$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$	$\begin{pmatrix} -1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$
6	$\begin{pmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \end{pmatrix}$	$\begin{pmatrix} -1 & -1 & 0 & 0 \\ 0 & 1 & -1 & 1 \end{pmatrix}$



in the exporting unit and the importing unit respectively. The transportation costs and production costs are also approximated by second degree polynomials as follows:

$$\begin{aligned}\text{Transportation Cost} &= \tau y_2^2 + \omega y_2, \\ \text{Production Cost} &= \gamma_{k1} y_3^2 + \delta_{k1} y_3 \\ &\quad + \gamma_{k2} y_5^2 + \delta_{k2} y_5.\end{aligned}$$

Here, the subscript k distinguishes the various periods within the year.

The net incremental value function for period k now can be written

$$\begin{aligned}F(y_1, y_2, y_3, y_4, y_5) &= \alpha_1 y_1^2 + \beta_1 y_1 + \alpha_2 y_4^2 + \beta_2 y_4 \\ &\quad - \tau y_2^2 - \omega y_2 - \gamma_{k1} y_3^2 - \delta_{k1} y_3 \\ &\quad - \gamma_{k2} y_5^2 - \delta_{k2} y_5.\end{aligned}$$

Table 4.2 gives this function together with a resolution of the period's value by producing units and by market agents. The net incremental value function is shown in the lower right box, and labeled 1. The various components given in the other boxes can be built up from the money flows shown in Figure 4.1, which distinguish producers, traders and consumers in each unit. In this classification system, traders are considered to buy\* from producers at the time of planting. Thus, the producers take no risks

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\*in the futures market

Table 4.2 Incremental Value Functions for Period k			
	Exporter (Unit 1)	Importer (Unit 2)	Total (Unit 1 + Unit 2)
Consumers' Gain	<sup>3</sup> $-\alpha_1 y_1^2$	<sup>5</sup> $-\alpha_2 y_4^2$	$-\alpha_1 y_1^2 - \alpha_2 y_4^2$
Traders' Gain	$(2\alpha_1 y_1 + \beta_1)(y_1 + y_2)$ $- (2\gamma_{k1} y_3 + \delta_{k1}) y_3$	$(2\alpha_2 y_4 + \beta_2) y_4 - \tau y_2^2$ $- (2\alpha_1 y_1 + \beta_1 + \omega) y_2$ $- (2\gamma_{k2} y_5 + \delta_{k2}) y_5$	$(2\alpha_1 y_1 + \beta_1) y_1 - (2\gamma_{k1} y_3 + \delta_{k1}) y_3$ $+ (2\alpha_2 y_4 + \beta_2) y_4 - (2\gamma_{k2} y_5 + \delta_{k2}) y_5$ $- \tau y_2^2 - \omega y_2$
Producers' Gain	<sup>4</sup> $\gamma_{k1} y_3^2$	<sup>6</sup> $\gamma_{k2} y_5^2$	$\gamma_{k1} y_3^2 + \gamma_{k2} y_5^2$
Total Net Welfare	<sup>2</sup> $\alpha_1 y_1^2 + 2\alpha_1 y_1 y_2 + \beta_1 (y_1 + y_2)$ $-\gamma_{k1} y_3^2 - \delta_{k1} y_3$	$\alpha_2 y_4^2 + \beta_2 y_4 - (2\alpha_1 y_1 + \beta_1 - \omega) y_2$ $- \tau y_2^2 - \gamma_{k2} y_5^2 - \delta_{k2} y_5$	<sup>1</sup> $\alpha_1 y_1^2 + \beta_1 y_1 + \alpha_2 y_4^2 + \beta_2 y_4$ $- \tau y_2^2 - \omega y_2 - \gamma_{k1} y_3^2$ $- \delta_{k1} y_3 - \gamma_{k2} y_5^2 - \delta_{k2} y_5$

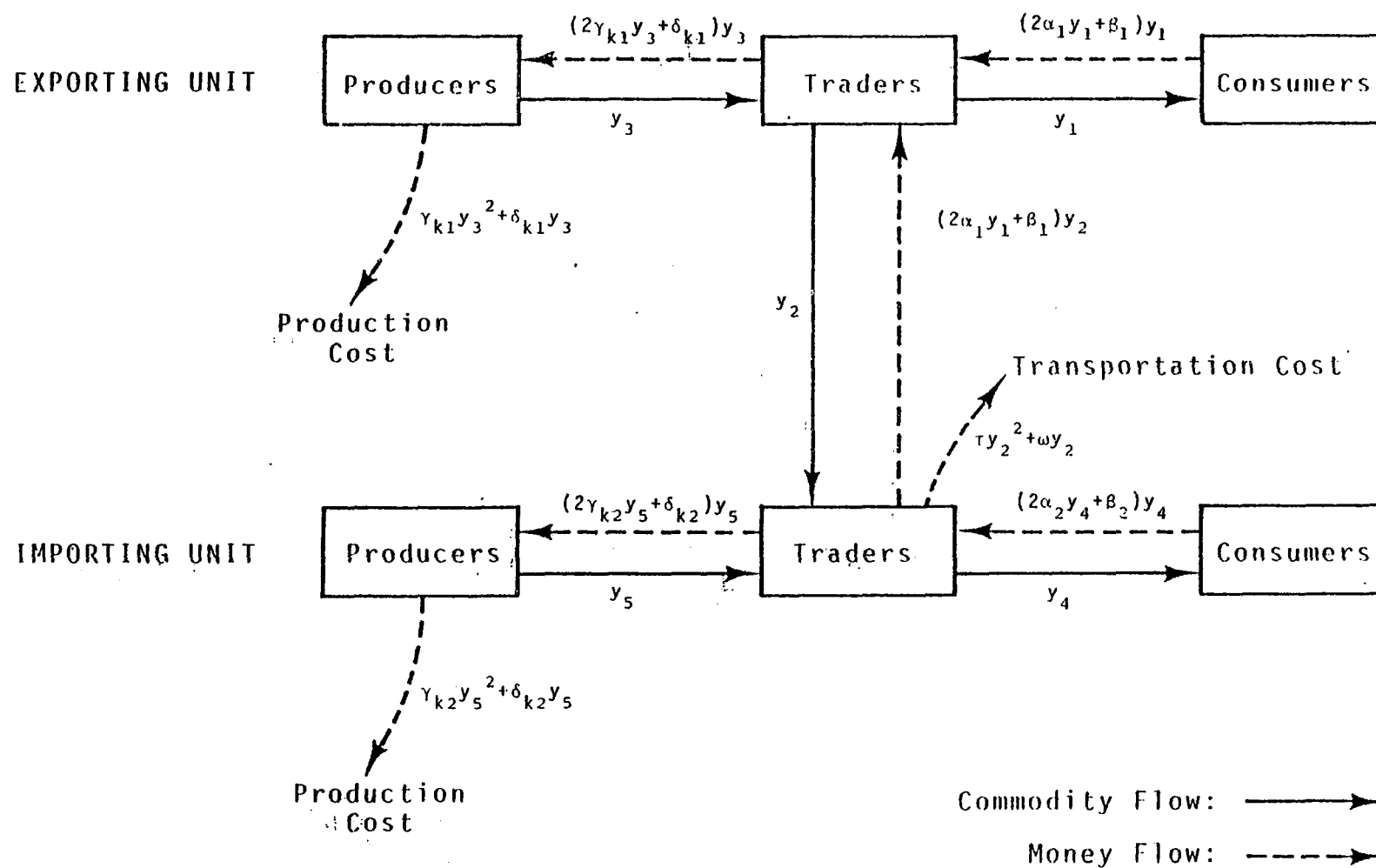


Figure 4.1 Flows Among Market Agents and Costs

associated with yield variability. Of course, the same individual or firm could function simultaneously as a producer and a trader by making his sale at harvest time or after. Our classification of market agents is really a classification of functions, not necessarily of individuals. Producers incur production costs at the time of planting and collect revenues at the same time from the traders of their own unit based on a futures price. Equilibrium requires that this price be equal to the marginal cost of production, which is  $2\gamma_{k1}y_3 + \delta_{k1}$  in the exporting unit and  $2\gamma_{k2}y_5 + \delta_{k2}$  in the importing unit. Traders in the importing unit pay the transportation costs on the quantity  $y_2$  which is imported, and pay for the commodity itself the price prevailing in the exporting unit, which is  $2\alpha_1y_1 + \beta_1$ .

The gains accruing to each category of market agent are easily read off from Figure 4.1 by taking the difference of the incoming and outgoing money flows. These differences form the expressions given in Table 4.2. All twelve value functions are of interest in our model, but some can be calculated as sums of others. Therefore, we specify only six of them for direct calculation by solution of functional equations. These six are indicated by numerals in the upper left corners of the boxes in Table 4.2.

Algebraically, we denote the six incremental value functions  $F_{1k}$ ,  $F_{2k}$ , ...,  $F_{6k}$ , where  $k$  is the period of the year. These functions can be expressed in terms of coefficient matrices as follows.

$$F_{ik}(Y) = Y'A_{ik}Y + Y'B_{ik} \quad (4.2)$$

where  $A_{ik}$  are  $5 \times 5$  matrices and  $B_{ik}$  are vectors of five components. These coefficients are collected in Table 4.3.

Table 4.3 Incremental Value Function Coefficients

No.	Name	A	B	No.	Name	A	B
1	Total	$\begin{pmatrix} \alpha_1 & 0 & 0 & 0 & 0 \\ 0 & -\tau & 0 & 0 & 0 \\ 0 & 0 & -\gamma_{k1} & 0 & 0 \\ 0 & 0 & 0 & \alpha_2 & 0 \\ 0 & 0 & 0 & 0 & -\gamma_{k2} \end{pmatrix}$	$\begin{pmatrix} \beta_1 \\ -\omega \\ -\delta_{k1} \\ \beta_2 \\ \delta_{k2} \end{pmatrix}$	4	Exporter Producers' Gain	$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \gamma_{k1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$
2	Exporter Net Welfare	$\begin{pmatrix} \alpha_1 & \alpha_1 & 0 & 0 & 0 \\ \alpha_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & -\gamma_{k1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$	$\begin{pmatrix} \beta_2 \\ \beta_2 \\ -\delta_{k1} \\ 0 \\ 0 \end{pmatrix}$	5	Importer Consumers' Gain	$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\alpha_2 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$
3	Exporter Consumers' Gain	$\begin{pmatrix} -\alpha_1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$	$\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$	6	Importer Producers' Gain	$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \gamma_{k2} \end{pmatrix}$	$\begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$

The fundamental cumulative value function at time  $t$ , which is the discounted sum of  $F_{1k}$ 's,  $k \geq t$ , will be denoted  $V_{1t}$ . The auxiliary value functions, associated with  $F_{2k}, \dots, F_{6k}$ , will be denoted  $V_{2t}, \dots, V_{6t}$ . Each is approximated by a second degree polynomial in  $X_t$ , as follows.

$$V_{it}(x_t) = X_t' Q_{it} X_t + X_t' L_{it} + K_{it}, \quad (4.3)$$

where each  $Q_{it}$  is a symmetric matrix,  $L_{it}$  is a vector, and  $K_{it}$  is a scalar. Our basic computational task is to find  $Q_{it}$  and  $L_{it}$ , since this will enable us to determine the dependence of  $V_{it}(X_t)$  on the stochastic terms  $\phi_t$ .

#### 4.5 Dynamic Programming

The optimality principle for the system we are modeling can be written

$$V_{1t}(X) = \max_Y \{ F_{1t}(Y) + \rho \overline{V_{1(t+1)}(X_{t+1})} \} \quad (4.4)$$

where  $Y$  is subject to the constraints

$$Y \geq 0, \quad y_1 + y_2 \leq x_1, \quad y_4 \leq x_2.$$

As before, the bar indicates the mean value with respect to the random variable  $\phi_t$ . Using Equations 4.1, 4.2 and 4.3, the maximand can be written

$$Y'E_1 Y + Y'F_1 + G_1$$

where

$$\begin{aligned} E_1 &= A_{1t} + \rho N_t' Q_{1(t+1)} N_t, \\ F_1 &= B_{1t} + 2\rho Q_{1(t+1)} M_t' X N_t + \rho L_{1(t+1)}' N_t, \\ G_1 &= \rho [X' M_t' Q_{1(t+1)} M_t X + L_{1(t+1)}' M_t X + K_{1(t+1)} \\ &\quad + \overline{\phi_t' Q_{1(t+1)} \phi_t}]. \end{aligned} \quad (4.5)$$

The evaluation of Equation 4.4 for a given value of  $X$  is thus a quadratic programming problem with five variables and two constraints. It can be solved easily, provided the values of  $Q_1(t+1)$ ,  $L_1(t+1)$  and  $K_1(t+1)$  are known.\* If it happens that the constraints on  $Y$  in this maximization are not encountered, then the maximizer  $Y^*$  is given by

\*This quadratic programming problem can be put in the form

$$\text{Maximize } F(y) \quad (=Y'E_1Y + Y'F_1 + G_1)$$

$$\text{Subject to:} \quad CY \leq D, \quad Y \leq 0,$$

where

$$C = \begin{pmatrix} 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{pmatrix}$$

and

$$D = \begin{pmatrix} X_1 \\ X_2 \end{pmatrix}$$

The solution procedure used is based on manifold suboptimization. It finds the exact optimal solution to problems of the form

$$\text{Maximize } f(Y)$$

$$\text{Subject to:} \quad CY = D, \quad Y \geq 0, \quad (1)$$

where  $f$  is a concave continuously differentiable function. The optimal solution  $Y^*$  may have some zero components. We let

$$T^* = \{i | Y_i^* = 0\}$$

We then note that  $Y^*$  solves the simpler problem:

$$\text{Maximize } f(Y)$$

$$\text{Subject to:} \quad CY = D, \quad Y_i = 0, \quad i \in T^* \quad (2)$$

To solve (1), we iteratively solve problems of the form (2), where  $T$  changes from iteration to iteration. At each iteration, optimality is checked via the Kuhn-Tucker conditions. If the solution to (2) is not optimal for (1), an appropriate change in  $T$  is indicated, and the procedure is repeated.

If the dimension of  $Y$  is  $d$ , then there are  $2^d$  possible choices for  $T$ . This is a finite number if  $d$  is finite. Therefore, since we can solve each problem of form (2) in a finite number of iterations, we can solve (1) in a finite number of iterations.

$$Y^* = -1/2E_1^{-1}F_1,$$

so that  $V_{1t}$  is a quadratic function of  $X$ . If this were always the case, we could expand  $V_{1t}$  explicitly in  $X$  and read off its coefficients  $Q_{1t}$ ,  $L_{1t}$  and  $K_{1t}$ . However, the constraints may be encountered, so  $V_{1t}$  is not quadratic in  $X$ . To approximate it by a quadratic form, we select a grid of points  $X_1, \dots, X_n$  in the state space at time  $t$ . We evaluate  $V_{1t}$  at each of these points (by quadratic programming), and then determine the coefficients  $Q_{1t}$ ,  $L_{1t}$  and  $K_{1t}$  of the quadratic polynomial giving the least squares fit to  $V_{1t}$  at the selected points. This two-step procedure--quadratic programming followed by least squares approximation--provides value function coefficients  $Q_{1t}$ ,  $L_{1t}$ , and  $K_{1t}$ , assuming  $Q_{1(t+1)}$ ,  $L_{1(t+1)}$  and  $K_{1(t+1)}$  are known. At the same time, the procedure is used to obtain the auxiliary value function coefficients  $Q_{it}$ ,  $L_{it}$  and  $K_{it}$  for  $i = 2, \dots, 6$ , since  $V_{it}(X)$  are given by

$$V_{it}(X) = Y^*{}'E_iY^* + Y^*{}'F_i + G_i$$

where  $Y^*$  is the maximizer in Equation 4.4 and

$$\begin{aligned} E_i &= A_{it} + \rho N_t' Q_{i(t+1)} N_t, \\ F_i &= B_{it} + 2\rho Q_{i(t+1)} M_t' X N_t + \rho L_{i(t+1)} N_t, \\ G_i &= \rho [X' M_t' Q_{i(t+1)} M_t' X + L_{i(t+1)} M_t' X + K_{i(t+1)} \\ &\quad + \overline{\phi_t' Q_{i(t+1)} \phi_t}]. \end{aligned}$$

Thus, the five auxiliary value functions are approximated by least squares on the same grid as is used for  $V_{1t}$ .



Starting with terminal value assumptions on  $V_{ij}$ ,  $i = 1, \dots, 6$ , corresponding to some year far in the future, we can repeat the backward induction steps described above to obtain first  $V_{im}$ ,  $i = 1, \dots$ , then  $V_{i(m-1)}$ ,  $i = 1, \dots, 6$ , etc. After  $m$  steps, we obtain a new set  $V_{im}$ ,  $i = 1, \dots, 6$ , this time corresponding to one year earlier. Continuing the cycle through the  $m$  periods each year until we get back to the present, we finally obtain the desired functions. Because of the use of discounting, it makes no difference what terminal value assumptions are made, provided we begin the backward induction far enough in the future.

Another viewpoint on the same calculation is the following. Because we are building a steady state model the value functions should be identical at times one year apart. Thus, for any fixed  $X$ ,  $V_{it}(X) = V_{i(t+m)}(X)$ . If  $\Gamma$  stands for  $m$  steps of backward induction as described above, then we must have

$$\Gamma V_{it} = V_{it}, \quad i = 1, \dots, 6; \quad t = 1, \dots, m.$$

Starting with any approximations  $V_{it}^1$ , we can produce a sequence of approximations  $V_{it}^1, V_{it}^2, V_{it}^3, \dots$  by repeating  $\Gamma$ . Thus,

$$V_{it}^{n+1} = \Gamma V_{it}^n.$$

When successive approximations are close enough to equal, they can be taken as the solution of

$$\Gamma V_{it} = V_{it}.$$

This convergence does occur in the model, because of the presence of the discount factor  $\rho$  in the optimality principle (4.4).

#### 4.6 Value of Information

The quality of information in our model is represented in the random variables  $\phi_t$ .<sup>\*</sup> A direct way of finding the value of improved information is as follows. Using  $\phi_t$  corresponding to the current information system, and the coefficients  $Q_{i1}$ ,  $L_{i1}$ , and  $K_{i1}$ ,  $i = 1, \dots, 6$ , as determined by the dynamic programming procedure outlined above, one evaluates

$$V_{i1}(X) = X'Q_{i1}X + X'L_{i1} + K_{i1}, \quad i = 1, \dots, 6,$$

for  $X$  equal to current stock levels at the beginning of the crop year. Then, using  $\phi_t$  corresponding to the improved information system, one recalculates the coefficients and reevaluates  $V_{i1}(X)$ . The difference between these two calculations of  $V_{i1}(X)$  is the present value of the improvement of information in category  $i$ ,  $i = 1, \dots, 6$ . In particular, for  $i = 1$  and  $1 = 2$ , one obtains total worldwide value of information, and value to the exporting unit, respectively.

A shortcut is possible in the procedure just outlined, however, which results in a considerable saving of computational effort. The basic idea is that the difference in  $V_{i1}(X)$  due to a change in the  $\phi_t$ 's can be expressed in terms of the  $Q_{it}$ 's alone (which do not depend on the  $\phi_t$ 's), without knowledge of the  $L_{it}$ 's or the  $K_{it}$ 's. Because of this, it is not necessary to continue iterations of the dynamic programming procedure until convergence is achieved in all three coefficient arrays. It turns out that convergence is quite rapid in  $Q_{it}$ , but slower in  $L_{it}$ , and very slow in  $K_{it}$ . Thus, it saves calculational effort to discontinue iterations as soon as convergence is achieved in  $Q_{it}$ . Further, this dynamic programming calculation need be done only once, since its essential output, the array of  $Q_{it}$ 's, is the same for the two information systems. The next few paragraphs work out these ideas in detail.

---

<sup>\*</sup>See Equation (4.1).

For a given period  $t$ , and a given value of  $X$ , let  $Y^*$  be the maximizer in the optimality principle

$$V_{1t}(X) = \max_Y \left\{ F_{1t}(Y) + \rho \overline{V_{1(t+1)}(X_{t+1})} \right\}.$$

Putting in  $Y^*$  and the state transformation, we obtain

$$V_{1t}(X) = F_{1t}(Y^*) + \rho [V_{1(t+1)}(M_t X + N_t Y^* + \Phi_t)].$$

Since  $\Phi_t$  has mean 0, this can be written

$$\begin{aligned} V_{1t}(X) = F_{1t}(Y^*) + \rho [V_{1(t+1)}(M_t X + N_t Y^*) \\ + \overline{\Phi_t' Q_{1(t+1)} \Phi_t}], \end{aligned}$$

where we have used the expansion (Equation 4.3) of  $V_{1(t+1)}$ . Notice that the function  $f$  given by

$$F(X, T, \Sigma^2) = F_{1t}(Y^*) + \rho [V_{1(t+1)}(M_t X + N_t Y^*) + \Sigma^2]$$

has the partial derivative  $\frac{\partial f}{\partial \Sigma^2} = \rho$ , which is independent of  $X$ . Thus, the least squares approximation to  $V_{1(t)}$  will be affected by

$$\Sigma_{t+1}^2 = \overline{\Phi_t' Q_{1(t+1)} \Phi_t}$$

only in its constant term,  $K_{1t}$ . The total derivative of  $V_{1t}(X)$  with respect to  $\Sigma_{t+1}^2$  consists of the partial derivative  $\rho$  plus the total derivative of

$$\rho V_{1(t+1)}(M_t X + N_t Y^*)$$

with respect to  $\Sigma_{t+1}^2$ . Using those expressions, we write the total derivatives of the starting (time 1) value functions with respect to the stochastic parameter  $\Sigma_{t+1}^2$  of time  $t$  as follows.

$$\frac{dV_{i1}}{d\Sigma_{t+1}^2} = \rho^t [1 + \rho^{m-t} \frac{dV_{i1}}{d\Sigma_{t+1}^2}] ,$$

$$\frac{dV_{i1}}{d\Sigma_{t+1}^2} = \frac{\rho^t}{1-\rho^m} .$$

Now let  $\Delta\Sigma_t^2$  be the difference in  $\Sigma_t^2$  in going from one information system to another. Then the corresponding difference in  $V_{i1}$  is given by

$$\begin{aligned} \Delta V_{i1} &= \frac{1}{1-\rho^m} [\rho\Delta\Sigma_2^2 + \rho^2\Delta\Sigma_3^2 + \dots + \rho^m\Delta\Sigma_1^2] \\ &= \frac{1}{r} [\rho^{1-m}\Delta\Sigma_2^2 + \rho^{2-m}\Delta\Sigma_3^2 + \dots + \Delta\Sigma_1^2] . \end{aligned}$$

Thus the annualized benefit in category  $i$  of the information improvement is represented by

$$\Delta\text{BENEFIT}_i = \rho^{1-m}\Delta\Sigma_2^2 + \dots + \rho\Delta\Sigma_m^2 + \Delta\Sigma_1^2 .$$

Notice that this calculation of the value of improved information requires only the  $Q_{it}$ 's and the variances and covariances of the  $\Phi_t$ 's. It does not require the  $K_{it}$  terms from which the  $\Sigma_t^2$ 's were extracted. Further, these  $K_{it}$  terms themselves affect neither the maximizers  $Y^*$  in the optimality principle, nor the variable terms in the least squares fit. Thus, the coefficients  $Q_{it}$  and  $L_{it}$  do not depend on any  $K_{it}$ .

#### 4.7 Grid for Value Function Approximation

As mentioned in Section 4.5, a grid of points  $X_1, \dots, X_n$  is selected in the state space for each time  $t$ ,  $t = 1, \dots, m$ . Initially, these grid points are selected by judgment, so that the points cover the expected range of variation of the state vector. After solution of the optimality principle (Equation 4.4), we can explicitly evaluate the state transformation, and thus track the development of the state vector through many years. Using Monte Carlo simulation we find the probability distribution of the state vector for each time  $t$ . Then we adjust the grid points to conform to this distribution, and repeat the procedure. This sequence--solution of optimality principle followed by simulation--is continued until convergence is attained.

At a given time  $t$ , the grid represents a discrete equiprobable distribution. If  $d$  is the dimension of the state space at time  $t$ , and  $n$  is the number of values of each coordinate represented in the grid, there are  $n^d$  points in the grid. In each coordinate, the values are equally spaced. Such a grid is completely determined by the mean and standard deviation of each coordinate. Thus, only these statistics are collected from the simulations and convergence is considered to be achieved when the means and standard deviation of each coordinate at each time of year have stabilized.

## 5. APPLICATION TO WHEAT, CORN, AND SOYBEANS

### 5.1 Numerical Calculations for Wheat

The crop year is divided into six periods, the first one beginning June 1, when consumption may be taken from the new crop instead of from storage. In the United States, the exporting unit in the model, the production decision for winter wheat is considered to occur during the second period, and the first sowing is accomplished October 1, the starting date for the third period. The United States spring wheat production decision is considered to occur during the fifth period, with sowing accomplished April 1, the start of the sixth period. In the rest of the world, the importing unit of the model, three components of the annual wheat crop are considered. These are winter and spring wheat in the northern hemisphere, and winter wheat in the southern hemisphere. These northern hemisphere components are considered to be sowed October 1 and April 1 as in the United States, while sowing of the southern hemisphere crop is considered to be accomplished June 1, the beginning of the first period.

The cost and demand function parameters are based on average quantities produced and consumed in the two regions, and on elasticities of production and demand.

Tables 5.1 and 5.2 give these input quantities. The demand elasticities are from Bradford and Kelejian [6], the cost elasticities of production were selected by calibrating the model with respect to historical price variability, and the other data are based on USDA figures. From these data, we obtain the demand and cost function parameters given in Table 5.3.

Table 5.1 Average Annual Wheat Production by Time of Sowing, millions of metric tons

	Jun. 1	Aug. 1	Oct. 1	Dec. 1	Feb. 1	Apr. 1
United States	0	0	42.5	0	0	7.5
Rest of World	24	0	249	0	0	27

Table 5.2 Elasticities, Average Prices and Annual Consumption for Wheat

	United States	Rest of World
Price Elasticity of Demand	-.48	-.16
Cost Elasticity of Production	+.5	+.5
Average Price	132	140
Average Consumption	20	330

Table 5.3 Parameters of Demand and Cost Functions for Wheat

Function	Slope	Intercept
U.S. Demand*	-80.8	407
R.O.W. Demand*	-15.8	1015
U.S. Winter Wheat Production**	6.2	-132
U.S. Spring Wheat Production**	35.2	-132
R.O.W. Winter Wheat Production**	1.12	-140
R.O.W. Spring Wheat Production**	10.4	-140
R.O.W. Southern Hemisphere Production**	11.6	-140
Transportation**	.05	8
*Price depending on quantity per period. **Cost depending on quantity per period.		



The final input required to run the model of Chapter 4 is the matrix of forecast difference variances describing the performance of the current information system. This is given in Table 5.4, together with the forecast difference variances describing an improved system used for illustrative value of information calculations. The current system description is based on ECON's analysis of published data over a 14-year period, as described in Chapter 2. The "improved system" is one in which the variance of the error declines linearly to zero by April 1, the beginning of the final period, from a maximum of 405 (million tons)<sup>2</sup> at June 1. This decline pattern produces a standard error of 6 percent at August 1 and this (base case) improved system does not provide any new capability on the United States crop. Running the model with the current information system, convergence is obtained with the grid parameters as shown in Table 5.5 and quadratic value function coefficients as shown in Table 5.6.

The value functions are evaluated by taking the inner products of the coefficient arrays (Table 5.6) with the information variance arrays (as in Table 5.4). Actually, we are interested only in the differences in the value functions in going from one information system to another, so we form differences of the information variances, and take the inner products of these with the coefficient arrays. For example, the difference of the two variables arrays of Table 5.4 is

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 848 & 81 & 81 & 81 & 81 & -1172 \end{pmatrix}$$

To find the benefit of this information improvement to the United States, we take the inner product of this array with the fourth array in Table 5.6, or

Table 5.4 Description of Current and Improved Information Systems for Wheat

	Variance of Change in Production Estimate, (millions of tons) <sup>2</sup>					
	Prior-June	June -Aug.	Aug.-Oct.	Oct.-Dec.	Dec.-Feb.	Feb.-Apr.
Current System						
United States	6.39	5.95	.354	.424	0	0.192
Rest of World	895	0	0	0	0	1253
Improved System						
United States	6.39	5.95	.354	.424	0	0.192
Rest of World	1743	81	81	81	81	81

Source: Tables 2.6 and 2.7 with addition of 5 percent residual error for R.O.W. Current System and choice of 6 percent Case in Table 2.7.

Table 5.5 Grid Parameters at Convergence for Case of Wheat						
	State Vector by Time of Year					
	1	2	3	4	5	6
Means:						
U.S. Stocks	52.3	45.8	38.2	29.1	18.8	7.1
U.S. Growing	0	0	41.6	41.7	42.2	49.6
R.O.W. Stocks	311.0	261.8	211.3	162.3	114.9	68.9
R.O.W. Growing	0	0	242.5	242.5	242.5	269.4
Standard Deviations						
U.S. Stocks	2.8	3.6	2.9	2.8	3.4	4.5
U.S. Growing	0	0	2.8	3.0	3.2	3.2
R.O.W. Stocks	8.4	30.5	27.5	24.5	21.3	18.3
R.O.W. Growing	0	0	6.0	6.0	6.0	6.6

Table 5.6 Quadratic Term Coefficients of Value Functions for Wheat

United States	Aug.-Oct.	Oct.-Dec.	Dec.-Feb.	Feb.-Apr.	Apr.-Jun.	Jun.-Aug.	Aug.-Oct.	Oct.-Dec.	Dec.-Feb.	Feb.-Apr.
Consumers Gain	-.020 -.015	-.020 -.015	-.021 -.016	-.024 -.020	-.032 -.026	-.045 -.037	-.050 -.039	-.070 -.051	-.110 -.066	-5.271 .164
Traders Gain	-.582 .009	-.594 .009	-.608 .010	-.687 .002	-.755 .002	-.880 .002	-1.042 -.002	-1.123 -.004	-1.212 -.009	1.609 -.423
Producers Gain	.002 .003	.002 .003	.002 .002	.006 .007	.008 .009	.009 .011	.010 .013	.009 .015	.000 .017	.135 .038
Total Net Welfare	-.600 -.003	-.612 -.003	-.627 -.003	-.706 -.011	-.780 -.016	-.916 -.024	-1.082 -.028	-1.184 -.040	-1.322 -.058	-3.527 -.222
Rest of World										
Consumers Gain	-.421 -.441	-.431 -.450	-.446 -.465	-.554 -.573	-.681 -.705	-.860 -.895	-.991 -1.037	-1.173 -1.249	-1.368 -1.536	10.975 -3.579
Traders Gain	.855 .282	.872 .287	.897 .297	1.099 .429	1.329 .595	1.639 .790	1.923 .926	2.223 1.172	2.571 1.507	-7.039 3.819
Producers Gain	-.133 -.133	-.134 -.134	-.137 -.137	-.188 -.188	-.251 -.251	-.311 -.311	-.380 -.381	-.443 -.443	-.523 -.524	-2.800 -.820
Total Net Welfare	.300 -.291	.306 -.297	.314 -.304	.357 -.332	.396 -.362	.468 -.416	.552 -.491	.608 -.520	.681 -.553	1.086 -.580
Total (United States and Rest of World)										
Consumers Gain	-.441 -.456	-.451 -.465	-.466 -.481	-.578 -.593	-.713 -.731	-.905 -.932	-1.041 -1.076	-1.244 -1.300	-1.478 -1.602	5.704 -3.415
Traders Gain	.272 .291	.277 .296	.289 .307	.412 .430	.574 .597	.758 .791	.881 .925	1.100 1.168	1.360 1.498	-5.480 3.396
Producers Gain	-.131 -.130	-.133 -.131	-.136 -.134	-.182 -.181	-.244 -.243	-.302 -.300	-.370 -.368	-.433 -.428	-.523 -.507	-2.665 -.783
Total Net Welfare	-.300 -.294	-.306 -.300	-.313 -.308	-.348 -.343	-.383 -.377	-.448 -.440	-.530 -.519	-.576 -.561	-.641 -.611	-2.441 -.802

$$\begin{pmatrix} -.600 & -.612 & -.627 & -.706 & -.780 & -.916 & -1.082 & -1.184 & -1.322 & -3.527 \\ -.003 & -.003 & -.003 & -.011 & -.016 & -.024 & -.028 & -.040 & -.058 & -.222 \end{pmatrix}$$

and obtain an annual benefit of

\$234.8 million

Similarly, we can find the benefit of this improvement to various classes of market agents in the United States or the rest of the world by using the appropriate arrays from Table 5.6. The results of these calculations are given in Table 5.7, for the case of the particular conditions described above (Case 1) and for two alternative cases.

The United States benefit is realized through gains from world trade. As mentioned above, the benefit does not rest with the traders, but is passed on to farmers and consumers in a competitive market system with public information: to farmers since in free trade they will sell only at the "correct" market price which includes export opportunities; to consumers since in competitive markets possible initial "excess" profits will be passed on to consumers (particularly given the ease of entry into commodity trading) and, secondly, the general benefit accruing to consumers from free world trade, where the relative costs from exports are always more than offset by the relative gains from increased imports.

Whereas, the total net gains to the United States can be determined quite precisely--within the range of sensitivities explored in Chapter 6--the final share in these benefits by consumers and farmers is much more difficult to determine and extremely sensitive to even small changes in assumptions and parameter values [6]. Claims to the contrary, e.g. that only farmers, or consumers, or traders would unduly benefit from improved public information should be regarded with caution.

Table 5.7 Benefits of Improved Information on Wheat by Classes of Market Agents, millions of 1975 dollars annually

	Case 1* (6%)	Case 2* (3%)	Case 3* (9%)	Case 4* (GE)
United States				
Consumers' Gain	[-230]**	[-236]**	[-220]**	[-233]**
Traders' Gain	497	524	452	530
Producers' Gain	[-32]	[-35]	[-27]	[-40]
Total Net Welfare	235	253	205	258
Rest of World				
Consumers' Gain	[3214]**	[3504]**	[2731]**	[3751]**
Traders' Gain	[-3616]	[-3934]	[-3085]	[-4222]
Producers' Gain	[614]	[688]	[490]	[794]
Total Net Welfare	212	258	136	322
Total Net Gain (United States and Rest of World)	447	511	341	580

\* Residual standard errors of current system assumed to be 5 percent in rest of the world and zero in the United States.

\*\* Numbers in [] brackets show first order effects only. In a competitive market system and public information all benefits are expected to accrue to farmers (producers) and consumers without any relative gains or losses to traders.

The United States benefit is realized through the trader's income.\*

In terms of price stability, improved information enables the United States to absorb some of the excessive price fluctuations of the world market. The rest of the world pays for this service through its purchase of United States exports.

That indeed farmers and consumers are the ultimate beneficiaries of improved public crop information is borne out by their respective insistence for precisely such public information and the general support that such activities (e.g., the Statistical Reporting Service and Foreign Agriculture Service of the USDA) have found over many decades--particularly in the United States. If anything the criticism from both groups--farmers and consumers--has been that not enough good information has been made public.

Both farmers and consumers of crops are numerous enough to guarantee a widespread, general impact of these benefits throughout all of the United States. No group seems particularly favored by improved crop information, if it is made public.

If the information were not made public, then indeed the gains from improved information might be restricted to the few traders--public or private--who have access to such information. The best way to assure the widest and broadest impact of improved crop information--and to avoid any misuse of such information--is to publish it.

The "cases" of improved information systems used for the calculations reported in Table 5.7 are the following:

- Case 1. Fractional standard error, 6 percent at August 1 in the rest of the world. No improvement over current system in the United States. This case is detailed in Table 5.4.

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\* As mentioned above, the benefit does not rest with the traders, but is eventually passed on to farmers and consumers.

Case 2. Fractional standard error 3 percent on August 1 in rest of the world. United States same as Case 1.

Case 3. Fractional standard error 9 percent on August 1 in rest of the world. United States same as Case 1.

Case 4. General Electric "Sigma Squared" results.

In each of these cases, the current information system is as described as in Table 5.4. This description incorporates the assumption that the "residual" standard error after all published estimates, including those published after the crop year, is 5 percent in the rest of the world, or 15 million tons, and zero in the United States. Data do not presently exist to tie down this residual error precisely, but it may well be greater than 5 percent. (See Appendix A2 for further discussion of this point.)

## 5.2 Numerical Calculations for Corn and Soybeans

As in the case of wheat, we divide the crop year into six periods. For corn, the crop year is considered to begin October 1. We consider the world crop in three components. United States production, for which the production decision is made during the fourth period (April 1 - June 1) and the first sowing is accomplished by June 1; rest of the world production in the northern hemisphere, following the same calendar; and rest of the world production decision is made during the first period (October 1 - December 1) and the first sowing is accomplished by December 1.

The calendar for soybeans is similar to the one for corn--the only difference is that each event takes place one month earlier. Thus, the crop year begins September 1, and one begins tracking the growing crops in March in the northern hemisphere and November in the southern hemisphere.

The input data for the corn and soybeans calculations are given in Table 5.8 and 5.9. These are just as used in the distribution study [2].



Table 5.8    Average Annual Corn and Soybeans Production by Period of Sowing millions of metric tons							
		Period					
		1	2	3	4	5	6
Corn	U.S.	0	0	0	0	145.0	0
	R.O.W.	0	33.8	0	0	136.3	0
Soybean	U.S.	0	0	0	0	40.11	0
	... R.O.W.	0	10.08	0	0	11.08	0

Table 5.9 Elasticities, Average Prices and Annual Consumption for Corn and Soybeans

		Elasticity		Price	Consumption
		Demand	Production	\$ / ton	millions of tons
Corn	U.S.	-.36	+.5	124	115
	R.O.W.	-.36	+.5	134	200.1
Soybean	U.S.	- .4	+.5	220	24.1
	R.O.W.	- .4	+.5	230	37.2

The variances describing the current information systems are given in Table 5.10. These are based on the statistical analyses of the distribution study, with two changes. The variance sequence for corn in the present study incorporates an explicit assumption that the residual standard error of the rest of the world estimate is five percent. And in the case of soybeans, the data from the distribution study are adapted to our six-period model. The distribution model was used with four periods per year. Variances describing improved systems having standard error at time 1 of 6 percent and 3 percent on the rest of the world crop are also given in Table 5.11.

Coefficients of the United States total value function after convergence of the model are given in Table 5.11. When these are combined with the information system variances, benefits to the United States are calculated as given in Table 5.12.

Table 5.10 Description of Current and Improved Information Systems for Corn and Soybeans

	Variance of Change in Production Estimate, (millions of tons) <sup>2</sup>					
	Current System		Improved System (6%)		Improved System (3%)	
	U.S.	R.O.W.	U.S.	R.O.W.	U.S.	R.O.W.
<b>Corn</b>						
Prior-Apr.	0	98	0	0	0	0
Apr.-Jun.	132.37	18.4	132.37	0	132.37	0
Jun.-Aug.	66.69	120.7	66.69	0	66.69	0
Aug.-Oct.	35.61	360.7	35.61	2319	35.61	2397.8
Oct.-Dec.	10.24	984.3	10.24	0	10.24	0
Dec.-Feb.	0	323.9	0	0	0	0
Feb.-Apr.	0	151.8	0	0	0	0
Apr.-Jun.	0	149.7	0	0	0	0
Jun.-Final	7.93	216.3	7.93	104.8	7.93	26.04
<b>Soybeans</b>						
Prior-Mar.	8.09	0	8.09	0	8.09	0
Mar.-May	0	0	0	0	0	0
May.-Jul.	6.58	0	6.58	0	6.58	0
Jul.-Sep.	6.66	0	6.66	8.5	6.66	9.71
Sep.-Nov	0	6.7	0	0	0	0
Nov.-Jan.	1.24	0	1.24	0	1.24	0
Jan.-Mar.	0	0	0	0	0	0
Mar.-May	0	0	0	0	0	0
May-Final	.13	3.41	.13	1.61	.13	0.4

Table 5.11 Quadratic Term Coefficients of United States Total Value Functions for Corn and Soybeans.

Coefficient of	Corn									
U.S. Variances	.000	-.155	-.166	-.169	-.186	-.192	-.199	-.199	-.233	-.249
R.O.W. Variances	.043	.054	.055	.056	.060	.061	.060	.060	.060	-.196
Coefficient of	Soybeans									
U.S. Variances	0	-3.923	-4.072	-4.299	-5.000	-5.510	-6.138	-6.138	-7.926	-28.280
R.O.W. Variances	-.175	-.768	-.760	-.853	-1.065	-1.294	-1.597	-1.597	-2.339	-3.774

Table 5.12 Unites States Benefits of Improved Information on Corn and Soybeans, millions of 1975 dollars annually		
Improved System	Corn	Soybeans
Case 1 (6%)	48.0	6.68
Case 2 (3%)	87.3	10.21
Case 3 (1.5%)	97.0	11.09

## 6. COMMENTS ON NUMERICAL RESULTS AND SENSITIVITY ANALYSES

The benefits of improved information quoted above are all "integrated benefits," that is, they are based on simultaneous response of production decisions and distribution decisions to the information available in the markets. There is no meaningful way to decompose the benefits into components referring to distribution and production separately. Thus, the methods of this report and its numerical results supersede, rather than supplement, the results of the ECON distribution studies.

The following is an analysis of the sensitivity to variations in selected input quantities of the results presented in Chapter 5. We present only the effects of these variations on the total United States benefits and total rest of the world benefits, and only for the case of wheat.

The sensitivity analyses are performed with respect to the following parameters: demand elasticity in the United States; demand elasticity in the rest of the world; production elasticity; residual error of rest of the world production estimate (current system); and discount rate. In each case, the improved (LACIE) information system is assumed to provide production estimates of 6 percent standard error at August 1 for the rest of the world, and to provide no change in accuracy for the United States.

Some research to date indicates that LANDSAT data may be helpful also for domestic (U.S.) wheat crop estimation. Any capability of such improvements will add to total U.S. benefits. (For reference see [3].)

Table 6.1 gives the ranges for the selected parameters. The base case values are underlined. Table 6.2 gives the results of varying these parameters individually.

Table 6.1 Range of Parameters for  
Sensitivity Analyses  
(Base Case Underlined)

Parameter	Range
Demand Elasticity	
United States	-.3 , <u>-.48</u> ,    -1.0
Rest of World	-.08 , <u>-.16</u> ,    -.32
Production Elasticity	.25 , <u>.5</u> ,    1.0
Residual Error in Rest of World	2% , <u>5%</u> ,    8%
Annual Discount Rate	6% , <u>10%</u>



Table 6.2 Sensitivity of United States and Rest of the World Benefits to Variations in Parameters

Parameter Varied from Base Case	Value of Varied Parameter	United States Benefit, \$ millions	Rest of World Benefit, \$ millions
R.O.W. Residual Error	2%	189	170
R.O.W. Residual Error	8%	296	286
Demand Elasticity (U.S., R.O.W.)	-.3 , -.08	173	223
Demand Elasticity (U.S., R.O.W.)	-1.0 , -.32	479	240
Demand Elasticity (U.S., R.O.W.)	-.1 , -.32	351	207
Production Elasticity	.25	259	157
Production Elasticity	1.0	211	244
Annual Discount Rate	6%	137	105
Base Line	(See Tables 5.1-5.2)	235	212

We notice that the benefit is quite sensitive to the demand elasticities, and less sensitive to the elasticities of production. As the absolute value of the United States demand elasticity increases, the United States benefit also increases, while an increase in the absolute value of the rest of the world demand elasticity produces a decline in benefits. As for production elasticity, the less production is able to respond to price changes, the greater the value of improved information. The benefits respond significantly to variations in the discount rate. This is not surprising since the discount rate determines the cost of holding inventories, and a fundamental source of benefit is the improved management of inventory levels. The sensitivities are illustrated in Figure 6.1.

If the discount rate were 0, inventory holding would be close to free, so inventories would be very large and timely information or production would be of no particular importance.

This finding is of particular significance since it demonstrates the role of improved information for economic systems with scarce resources (i.e. high opportunity costs of capital): the higher the real interest rate of an economic system, the greater the gains from improved information. In the United States this rate has been set at 10 percent by the Office of Management and Budget for purposes of government project evaluation.

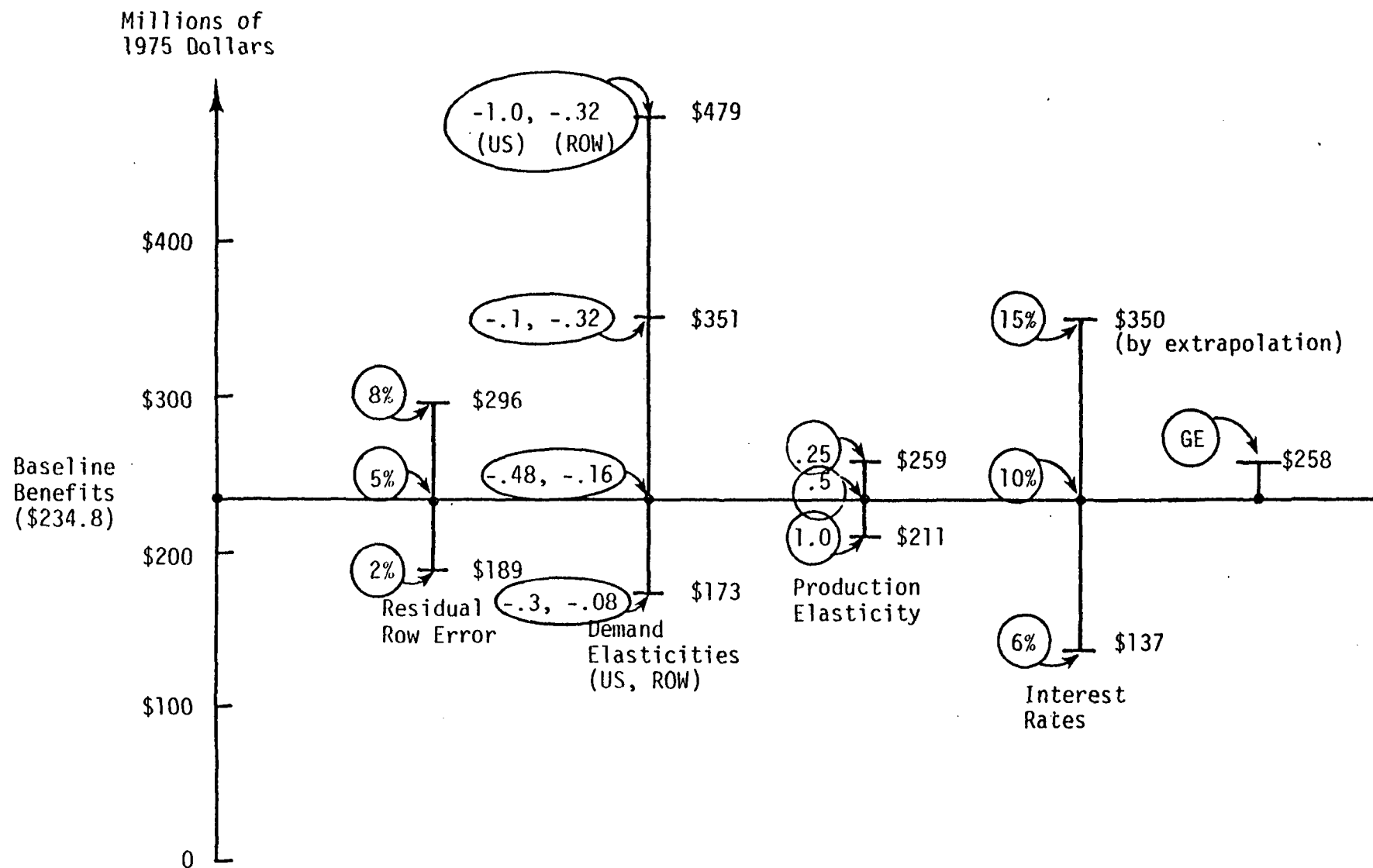


Figure 6.1 Sensitivity of Benefit Estimates to Changes in Key Economic Parameters

## REFERENCES

1. Andrews, J., "The Value of Domestic Production Information in Consumption Rate Determination for Wheat, Soybeans, and Small Grains," ECON, Inc., Report No. 75-127-3, Princeton, New Jersey, 1975.
2. Andrews, J., "A Distribution Benefits Model for Improved Information on Worldwide Crop Production," ECON, Inc., Report No. 76-104-1 (Volumes I and II), Princeton, New Jersey, 1976.
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10. Bradford, D. F. and H. H. Kelejian, "The Marginal Cost of Holding Wheat Inventories," Appendix B of [3], ECON, Inc., Princeton, New Jersey, 1974.
11. General Electric Space Division, "Sigma Squared Study," Final Report under Contract NAS 5-23412, MOD 30 (to be submitted to Goddard Space Flight Center in 1977).
12. Bellman, R. E. and Kalaba, Dynamic Programming and Modern Control Theory, Academic Press, New York, 1965.

## APPENDIX A1 THE ECON VALUE-OF-INFORMATION MODELS

Since early 1974, ECON, Incorporated has been undertaking research for the National Aeronautics and Space Administration on the value of improved agriculture crop information with particular attention to wheat. During that time, numerous reports have been submitted to NASA summarizing various aspects of the research effort. This appendix provides a brief bibliography and description of the reports, and outlines the approach taken in each.

BIBLIOGRAPHY OF THE ECON REPORTS ON THE VALUE OF  
IMPROVED CROP INFORMATION

- A.2.1 The Value of Improved (ERS) Information Based on Domestic Distribution Effects of U.S. Agriculture Crops, Report No. 74200210, Volume III, Part II, August 31, 1974.
- A.2.2 The Integrated Impact of Improved (ERS) Information on U.S. Agricultural Commodities, Report No. 74200210, Volume III, Part III, October 31, 1974.
- A.2.3 The Value of Domestic Production Information in Consumption Rate Determination for Wheat, Soybeans and Small Grains, Report No. 751273, August 31, 1975.
- A.2.4 The Value of Information for Crop Forecasting in a Market System, Report No. 751222A, August 31, 1975.
- A.2.5 The Value of Information for Crop Forecasting in a Market System with International Trade: Theory and Empirical Results, Report No. 751222C, August 31, 1975.
- A.2.6 United States Benefits of Improved Worldwide Wheat Crop Information From a Landsat System, Report No. 76-122-1B, January 31, 1976.
- A.2.7 United States Benefits of Improved Worldwide Wheat Crop Information From a Landsat System: Overview, Report No. 76-122-1A, January 30, 1976.
- A.2.8 A Distribution Benefits Model for Improved Information on Worldwide Crop Production: Application to Wheat (Volume I), Report No. 76-104-1A, August 31, 1976.

- A.2.9 : Application to Various Crops (Volume II), Report No. 76-104-1B, August 31, 1976.
- A.2.10 A Cost-Benefit Evaluation of the Landsat Follow-On Program, Working Paper prepared for NASA/GSFC under Contract No. NASW-2558, September 15, 1976.
- A.2.11 Technical Issues: Distribution Study (A Set of Eight Appendices to A.2.1), August 31, 1974.
- A.2.12 Sensitivity Analysis of the ECON Agriculture Information Models, Report No. 76-102-1A, August 31, 1976.

#### TECHNICAL APPROACHES

There are two major technical approaches with minor variations in each. These have come to be known as the Distribution Model and the Production Model, although these terms no longer accurately reflect the nature or methodology of the two approaches. A better terminology would be "Stochastic Optimization Model" for the former and "Econometric Simulation Model" for the latter. We will refer to these as SOM and ESM in the following lines.

#### DESCRIPTION OF THE ECON REPORTS ON THE VALUE OF IMPROVED CROP INFORMATION

- A.2.1 This report laid the foundation for the SOM approach. It developed the economic theory of the value of crop information in a market economy and applied the SOM method with finite planning horizon to a closed version of the U.S. wheat economy--exports were treated exogenously. In this report a Monte Carlo simulation of U.S. wheat production was employed.
- A.2.2 An early ESM study of world wheat and soybeans information with no separation of individual nations.
- A.2.3 In this report, ECON extended the SOM methodology for a closed U.S. economy to infinite planning horizons, and discovered a more elegant (mathematical) solution of the optimization. Application to wheat, soybeans and small grains. All production and exports were treated exogenously.
- A.2.4 This report contains analysis of a group of two-period market models which develops, in detail, the theory of how different inventory decision rules impact the economic welfare of consumers, producers, inventory-holders through a market system. The inventory decision rules are either "open-loop" or "closed-loop" and

relate to either "naive" or "sophisticated" forecasts of the supply of wheat in the next period giving rise to four cases.

- A.2.5      Extended the SOM methodology to a two-country world with one-way trade (the U.S. is assumed never to import). Application to wheat. Quarterly time grid. Open-loop decisions in determination of inventories and exports assumed. The stochastic optimization was not fully solved; instead a set of standard harvest patterns were selected and, based on these, the decisions were optimized.
- A.2.6      Applied ESM to a two-country world with one-way trade on a monthly grid. Thirteen econometric equations estimated including U.S. and Rest of World acreage response to prices. Thus the "production effect" was explicitly included in this model. Economic benefits were estimated for a Landsat system with a goal of ninety percent accuracy of wheat production forecasts ninety percent of the time.
- A.2.7      An executive summary of A.2.6.
- A.2.8      This report improved the solution techniques in the SOM methodology for a two-country world with one-way trade, and developed the mathematics for closed-loop decision making with infinite horizon. Production treated exogenously. Application to wheat distribution effects of improved crop information. (Volume I)
- A.2.9      Volume II applied the techniques of A.2.8 to corn, potatoes, sugar, soybeans and small grains.
- A.2.10     A summary of economic analyses performed by ECON of a number of earth observation applications of Landsat including the agricultural ones.
- A.2.11     A set of eight technical appendices to A.2.1 with subject matter as follows:
  - Appendix A   Estimating the Demand Function for Wheat: Total Domestic Disappearance and Human Uses Only
  - Appendix B   The Marginal Cost of Holding Wheat Inventories
  - Appendix C   The Derivation of the Value of Improved Measurements
  - Appendix D   Monte Carlo Simulation of Wheat Markets
  - Appendix E   The Harvest Patterns for Grains: 1969
  - Appendix F   The Variances of the Error Terms Due to Nature
  - Appendix G   The Value of Reducing the Time Delay in Obtaining Information
  - Appendix H   Basic Data Sources

- A.2.12 The sensitivity report reviewed fifteen major theoretical issues which had been raised by reviewers of the earlier reports, and analyzed mathematically and numerically the sensitivity of the economic benefits to the parametric values such as demand elasticities, and the theoretical assumptions.



## APPENDIX A2 THE ACCURACY OF CROP PRODUCTION FORECASTS

A2.1 Information

Although crop production forecasting by the U.S. Department of Agriculture is over a hundred years old, and although the importance of the forecasts for decision making is widely recognized, there is surprisingly little published work on the accuracy of the forecasts. There is a tendency on the part of those who have responsibility for producing forecasts to shy away from thorough evaluation of the quality of their work. Anyone who has tried to discuss the accuracy of forecasts with a forecaster will probably recognize this defensive attitude, and have his own pet theory for its existence. In the daily weather forecasts on television, for instance, one sees this attitude frequently displayed in the uneasy banter between the anchorman and the meteorologist. While not wishing to indulge in speculation on a sociological phenomenon, we want to start this essay with an unequivocal statement concerning the basis for our critical approach towards forecasting.

- Forecasting is difficult. While there exists a body of scientific techniques (see Theil's book [6] for a good review of economic forecasting), the construction of a public forecast still remains an art to some extent.

- We do not claim that there is necessarily a better way to achieve accurate and timely crop production forecasts in the United States. In fact, the existing American crop production forecasts are seen to be remarkably good when compared with similar forecasts in other countries.

- While individual crop forecasts may, in years with unusual economic or weather conditions, prove to be seriously in error, the characteristics of forecasts over a number of years, when compared with final estimates of the same quantity after harvest, should conform to certain logical principles.

Any well established forecast should involve, at the very least, the use of a scientifically designed sample and a statistical analysis of the data collected in that sample. Evaluation of the forecasts, ex post facto, is possible, and indeed desirable if the forecasting procedure meets these minimum standards. The responsible agency can use the evaluation to improve the quality of its forecasts in many cases, or if no change in forecasting procedures is indicated, to defend itself against critics in "bad" years.

In the next section we will review the existing federal government evaluation reports and published articles in professional journals on the accuracy of the United States crop production forecasts. Foremost among these is the 1972 study by Gunnelson, Dobson and Pamperin [1] which did address the accuracy issue and analyzed USDA crop forecasts for the years 1929 to 1970 in seven commodities, including spring and winter wheat. They found:

"USDA crop forecasts have become more accurate over time and exhibit desirable properties when appraised by the three criteria. Although this study revealed no serious inadequacies in the crop forecasts, the analysis identified a few persistent inaccuracies in the forecasts. Specifically, USDA tends to (1) underestimate crop size, (2) underestimate the size of changes in production from year-earlier levels, particularly when the changes are large, and (3) undercompensate for errors in previous forecasts when developing revised crop production forecasts. USDA officials and others responsible for improving the forecasts may wish to take these problems into account when methods of further improving the

accuracy of the forecasts are considered. Users also might take account of these tendencies when developing expectations concerning future crop production and price levels."

In subsequent sections, we analyze the wheat production forecasts for eleven wheat producing countries using a common evaluation criterion and considering only published forecasts from 1953 to 1974. This analysis serves as a basis for construction of a Monte Carlo simulation of improved wheat forecasts based on the LACIE goals. Results of the simulation are evaluated and compared with the actual forecasts for the same crop.

## A2.2 Review of Literature

H. Theil, in Economic Forecasts and Policy [6] noted the wide prevalence amongst business forecasts of the tendency to underestimate changes, and developed a statistic to detect this common prediction error. Gunnelson et al [1] used Theil's R-statistic as one of their three criteria for evaluating the USDA forecasts. Their evaluation found that the percentage of satisfactory ( $0 < R < 2$ ) first forecasts ranged from 61 percent to 75.6 percent, but that, of these, 62 percent underestimated the amount of change in production. They also found that the accuracy of first forecasts has "improved moderately in recent years," while second revisions show stronger evidence of improvement in performance. They consider the absolute level of percentage forecasting error in USDA crop forecasts to be acceptable, with the possible exception of the 9 to 11 percent errors in first forecasts for some crops, including wheat and corn. See Table A2.1 for these results.

The General Accounting Office's 1975 report to the Congress [2]

Table A2.1      Size of Average Absolute Percentage  
Forecasting Error in USDA Crop Forecasts  
by Commodity and Forecast Month, 1929-1970<sup>a</sup>

Commodity	Absolute Error by Forecast Month								
	December	April	May	June	July	August	September	October	November
	(Percentages)								
Barley					7.1	3.1	2.2		
Corn					9.2	5.9	4.0	2.8	2.0
Oats					4.9	2.9	2.4		
Potatoes						5.5	4.5	3.2	2.6
Soybeans						5.6 <sup>b</sup>	5.1 <sup>c</sup>	3.7 <sup>a</sup>	2.9 <sup>c</sup>
Spring Wheat					10.7	6.7	3.0	2.8	
Winter Wheat <sup>d</sup>	11.5	8.5	7.6	6.9	4.0	2.1			

<sup>a</sup> Forecasting error equals the absolute difference between the forecast and the December revised estimate expressed as a percentage of the December revised estimate.

<sup>b</sup> Percentages computed from data for 1944-1970.

<sup>c</sup> Percentages computed from data for 1940-1970.

<sup>d</sup> Error percentages for December winter wheat forecasts computed from data for 1942-1970. Error percentages for other winter wheat forecast months computed from 1920-1970 data.

Source: G. Gunnelson, W.D. Dobson and S. Pamperin: An Analysis of the Accuracy of USDA Crop Forecasts, American Journal of Agricultural Economics, November 1972.

on the need to improve agricultural commodity information reviewed the forecasts of acres harvested, yield, production, demand, prices and exports for recent years with particular attention to wheat and corn. The report found that "wheat and corn production forecasts were not very accurate in some of the marketing years we reviewed." But, for reasons detailed in the GAO's own discussions of acres harvested and yield, any crop production forecasting procedure will encounter some bad years. The evaluation analysis should not focus on the outliers (i.e., exceptionally large errors) but should instead report statistics based on many years as Gunnelson et al did. Thus we consider that the GAO report failed to provide a useful quantitative basis for its recommendations. This is not saying that their conclusions or recommendations were wrong; in fact we agree with most of them. There is, in our opinion, a need for periodic evaluation of the accuracy of the USDA forecasts as the GAO report recommends on page 22, but the technique for evaluating the forecasts should be much more analytical than the GAO report's own evaluation.

Very recently, in connection with the Office of Management and Budgets' Information Baseline for the LACIE Project, Fred Warren of USDA has prepared an analysis of the accuracy of wheat, acreage and yield production [3]. The standard errors of forecasts (deviations from final estimates<sup>\*</sup>) are examined for acreage, yield and production of winter wheat, spring wheat and all wheat. Forecast bias (systematic error) is treated in terms of the mean of the error and the coefficient of variation of forecast errors is used as a

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<sup>\*</sup> Postharvest estimates as published in December Crop Report of USDA.

measure of accuracy. This is very similar to the analytic technique which we have used (see Section A2.3) as we believe it is the correct one for the purpose of comparison with new technology forecasts. Some of the results of comparison with new technology forecasts. Some of the results obtained by Warren are reproduced here as Tables A2.2-A2.4. Note that the sample years selected for analysis by Warren are 1966 to 1975. Given the important changes in wheat economics in the last few years, the choice of sample is significant. Trends in acreage, yield and production do not influence forecast error analysis when the percentage deviations from final estimate are under consideration rather than the absolute deviations. But the difficulty of accurate crop forecasting has surely increased in the 1970s due to anomalous weather in several recent years and turbulent economic conditions. The future may resemble these "difficult" years more than the relatively stable period from the end of World War II to 1966. However, this point is not discussed in the Warren report. Since some of the current published SRS forecasts which could be subjected to error analysis did not exist in earlier years, and presumably some of the underlying procedures used to construct the forecasts have also changed, there may not have been much choice as to the period sampled for forecast error analysis.

The Task Force on Agricultural Forecasting [4] applied Theil's R-statistic to winter wheat forecasts in three crop reporting districts in Kansas and found considerably less propensity to underestimate the size of the crop than at the national level. No explanation was offered.

Table A2.2 Relative Forecast Errors of USDA/SRS Estimates of Acreage, Yield, and Production of all Winter Wheat, United States, 1966-1975

Forecast Date	Mean Forecast Error			CV of Forecast Error*			Probability of Forecast Error**		
	Area	Yield	Prod.	Area	Yield	Prod.	Area	Yield	Prod.
	percent of final			percent of final			percent		
Previous Dec.***	-1.5	1.4	-0.3	2.2	6.7	6.6	>99.9 (94)	86 (54)	87 (55)
May 1	-1.0	0.5	-0.5	1.5	7.8	7.0	>99.9 (99.6)	80 (48)	85 (52)
June 1	-1.0	0.5	-0.6	1.6	6.8	5.7	>99.9 99.4	86 89	92 82
July 1	-0.2	0.2	0.0	1.3	3.1	3.7	>99.9 (>99.9)	>99.9 (89)	99.3 (82)
Aug 1	-0.1	0.3	0.3	1.2	0.7	1.5	>99.9 (>99.9)	>99.9 (>99.9)	>99.9 (99.9)
Sept 1	-0.1	0.5	0.4	1.2	0.5	1.1	>99.9 (>99.9)	>99.9 (>99.9)	>99.9 (>99.9)

\*The coefficient of variation (cv = standard error ÷ mean) measures the relative precision of estimate.

\*\*The probability that a random selection of relative forecast errors from the universe defined by the study period would be less than ten percent (probabilities of error less than five percent in parentheses).

\*\*\* Estimates are for acres planted and average yield per acre planted.

Table A2.3 Relative Forecast Errors of USDA/SRS Forecast Estimates of Area, Yield, and Production of all Spring Wheat, United States, 1966-1975

Forecast Date	Mean Forecast Error			CV of Forecast Error*			Probability of Forecast Error**		
	Area	Yield	Prod.	Area	Yield	Prod.	Area	Yield	Prod.
	percent of final			percent of final			percent		
Apr 1***	-1.5	--	--	5.3	--	--	93 (64)	--	--
July 1	-0.6	2.5	1.6	2.3	14.0	12.2	>99.9 (96)	34 (28)	58 (32)
Aug 1	-0.7	-0.5	-1.3	2.1	8.0	6.0	>99.9 (97.6)	79 (47)	86 (54)
Sept 1	-0.7	0.0	-0.8	2.1	2.3	1.6	>99.9 (97.6)	>99.9 (97.0)	>99.9 (99.6)
Oct. 1	-0.7	0.1	-0.6	2.1	1.6	2.1	>99.9 (97.6)	>99.9 (99.8)	>99.9 (97.8)

\*The coefficient of variation (cv = standard error ÷ mean) measures the relative precision of estimate.

\*\*The probability that a random selection of relative forecast errors from the universe defined by the study period would be less than ten percent (probabilities of error less than five percent in parentheses).

\*\*\*Farmer's intentions to plant spring wheat, report issued in mid-March prior to 1971.



Table A2.4 Relative Forecast Errors of USDA/SRS Estimates of Acreage, Yield, and Production of all Wheat, United States, 1966-1975.

Forecast Date	Mean Forecast Error			CV of Forecast Error*			Probability of Forecast Error **		
	Area	Yield	Prod.	Area	Yield	Prod.	Area	Yield	Prod.
	percent of final			percent of final			percent		
July 1	-0.3	0.6	0.3	1.4	4.5	4.1	>99.9 (>99.9)	97.2 (73)	98.5 (98)
Aug 1	-0.3	0.2	-0.1	1.3	2.1	1.6	>99.9 (>99.9)	>99.9 (98.2)	>99.9 (99.8)
Sept. 1	-0.3	0.4	0.1	1.3	0.8	1.0	>99.9 (>99.9)	>99.9 (>99.9)	>99.9 (>99.9)

\*The coefficient of variation (cv = standard error ÷ mean) measures the relative precision of estimate.

\*\*The probability that a random selection of relative forecast errors from the universe defined by the study period would be less than ten percent (probabilities of error less than five percent in parentheses).

Presumably, if all the CRD's were examined, one would have to find a greater propensity to underestimate crop size in some of them.

Proceeding less mysteriously, the Task Force found that forecast error "seems to be smoothed as data is aggregated," based on a comparison of percentage forecast errors in Winter wheat at the Kansas CRD, the state of Kansas and the national levels in the 1960's.

### A2.3 ECON Analysis of USDA Wheat Production Forecasts

The purpose of the analysis is to provide a baseline for comparison with the "improved" forecasts which may result from operational implementation of the LACIE goals. Interest centers on production forecasts of all wheat for economic reasons [5]. When the wheat model reported in [5] was being developed, the sample period 1960-1974 was in use for all wheat producing countries included in the model. Since June forecasts of all wheat were discontinued by SRS in 1968, it was necessary to "construct" them from the June winter wheat forecast and the first forecast of spring wheat in July for 1968 to 1974. After discussions with the SRS staff, it was felt that this procedure impaired the validity of our analysis.

The improved procedure adopted as a result of these discussions is as follows:

For those years (1968-1974) in which no June forecast for all wheat production was published by USDA, we applied a correction factor (see below) to the June winter wheat forecast to obtain the best constructed June forecast for all wheat.

The correction factor was estimated from the ratios of the July all wheat forecast to the July winter wheat forecast by averaging the ratios over the years 1969-1973. Its value is 1.296.

United States Department of Agriculture July Forecasts  
(in millions of bushels)

(1) Year	(2) All Wheat	(3) Winter Wheat	(4) Ratio of (2) to (3)
1969	1425	1152	1.237
1970	1349	1094	1.233
1971	1548	1117	1.386
1972	1551	1195	1.298
1973	1749	1320	1.325
1969-73	7622	5878	1.296

Table A2.5 shows the SRS forecast data and final estimates for United States all wheat production.\* We dated the final estimates May of the postharvest year, thereby ignoring the true duration of the time period for revisions of the published final estimates.

If forecasts are to be correct on the average, i.e., unbiased, the mean error estimated from the sample should be nearly zero. Deviations from zero of the mean indicate a systematic tendency to underestimate or overestimate the crop production assuming that the final estimate itself is unbiased. Table A2.6 shows that the June forecast for all wheat production tended to underestimate the harvest in 1953 to 1967, as noted also by Gunnelson et al [1]. This bias declines in July, August and September. To gauge the accuracy of the forecasts for economic evaluation of alternative systems, we also derived the

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\* Given to ECON on February 12, 1976 by USDA/SRS from their files to use as source data in evaluation of SRS forecast accuracy.

Table A2.5  
U. S. ALL WHEAT PRODUCTION  
COMPARISON OF FORECAST AND PERCENT OF FINAL ESTIMATES

	June 1		July 1		August 1		September 1		October 1		
Year	Bushels	% of	Bushels	% of	Bushels	% of	Bushels	% of	Bushels	% of	Final Estimates
		Final		Final		Final		Final		Final	
	(Millions of Bushels)										
1953	1,133	96.5	1,175	100.1	1,203	102.5	1,169	99.7	1,163	99.2	1,173
1954	1,000	101.6	988	100.4	978	99.4	962	97.8	959	97.5	984
1955	845	90.2	850	91.8	911	97.2	917	97.8	916	97.7	937
1956	923	91.8	922	91.7	939	93.4	967	96.1	976	97.0	1,005
1957	971	101.5	940	98.4	915	95.7	923	96.6	927	97.0	956
1958	1,271	87.2	1,343	92.2	1,421	97.5	1,446	99.2	1,449	99.5	1,457
1959	1,162	105.7	1,155	103.3	1,119	100.1	1,116	99.9	1,117	100.0	1,116
1960	1,271	93.8	1,347	99.5	1,362	100.5	1,358	101.0	1,358	101.0	1,355
1961	1,343	109.0	1,259	102.2	1,204	97.7	1,210	98.2	1,211	98.3	1,252
1962	1,058	96.9	1,050	96.1	1,063	97.3	1,096	100.4	1,095	100.3	1,092
1963	1,084	94.5	1,111	96.8	1,151	100.3	1,134	98.9	1,133	98.8	1,147
1964	1,213	94.5	1,275	99.4	1,285	100.1	1,290	100.5	1,286	100.2	1,263
1965	1,283	97.5	1,354	102.9	1,376	104.6	1,358	103.2	1,354	102.9	1,316
1966	1,235	94.6	1,240	95.0	1,285	98.6	1,295	99.3	1,296	99.3	1,306
1967	1,550	102.8	1,596	105.9	1,511	100.2	1,543	102.4	1,554	103.1	1,503
1968	--	--	1,583	102.0	1,606	103.2	1,597	102.6	1,593	102.6	1,557
1969	--	--	1,425	98.8	1,459	101.1	1,457	101.0	1,456	100.9	1,443
1970	--	--	1,349	99.8	1,357	100.4	1,360	100.6	1,360	100.6	1,352
1971	--	--	1,548	95.7	1,601	98.9	1,625	100.4	1,628	100.6	1,618
1972	--	--	1,551	100.4	1,543	99.9	1,560	101.0	1,559	100.9	1,545
1973	--	--	1,749	102.6	1,717	100.7	1,727	101.3	1,727	101.3	1,705
1974	--	--	1,925	107.2	1,840	102.5	1,792	99.8	1,781	99.2	1,796
1975	--	--	2,187	102.5	2,141	100.3	2,136	100.1	2,138	100.2	2,134

Table A2.6 Forecast Error Analysis for United States All Wheat Production		
Month of Forecast	Mean Error in Percent Deviation (%)	Standard Error (1-Sigma) of Forecasts in Percent
June	-1.81	7.30
July	0.27	3.58
August	0.40	1.93
September	0.64	1.35
October	0.66	1.43
Source: ECON calculations based on USDA/SRS forecast summaries.		

1-sigma values shown in Table A2.6. For the years 1960 to 1974 the 1-sigma percentage error in United States all wheat production forecasts declined from about 7 percent in June to about 2 percent in September, with only a slight further improvement in the October revision.

Note that the Warren results [3] for 1966 to 1975 show a moderate improvement in the August and September forecasts when compared with our analysis of the 1960 to 1974 crop years, which probably reflects improvements in the SRS data processing and analysis between 1960 and 1974. Nevertheless, the overall picture presented by Warren is the same as ours, and the tools of analysis are similar. (We prefer the standard error of percentage deviations where Warren uses the coefficient of variation.)

In order to achieve the required form of input to the ECON economic models, it is necessary to have an accuracy level for twelve months of the year. Accordingly we have made the following two assumptions:

1. The market behaves as if it knows precisely the latest published forecast until a new forecast is published. Thus, forecasts may be "continued" through months where no new forecast is published.
2. In May, before the June forecast is available, the market can "anticipate" the production forecasting process by using the extrapolated trend value. For this purpose, a three-year moving average of final estimates is found to be suitable.

#### A2.4 Accuracy of Foreign Wheat Production Forecasts

The agricultural statistics from other countries vary enormously in quality, timeliness and comprehensiveness. In many cases they are not based on scientific sampling and measurement procedures and so cannot easily be considered in the same framework of error analysis applied to the United States. Furthermore, there does not appear to exist any reliable measure of the accuracy of most foreign crop survey statistics since it is hard to determine the true crop production even long after the event. To make matters worse, the deliberate falsification of publicly released crop production figures by some governments is strongly indicated.

Crop production forecast accuracies for individual countries and regions were calculated using FAO final harvest figures and a mixture of official and naive crop forecasts. The FAO final harvest figures typically are reported two to three years after the harvest. Using these "final" figures as the actual productions quantity, the standard deviations of the forecast and revision "errors" were calculated. Specifically, standard errors were calculated for each country for eleven months prior to harvest completion, the months in which the harvest was completed and for twelve months after the harvest was completed. These data were then reduced to a single crop year. This was done using the 1960 to 1974 FAO Production Yearbook and Commonwealth Secretariat's Grain Bulletin wheat data.

The production forecast figures consist of official forecasts and naive forecasts. The official forecasts are those made by official agencies, departments or institutions in each country or region. Often these forecasts are made in the harvest month.

However, the marketplace does not have the luxury of ignoring the likely or possible outcome prior to harvest. In order to fill the information void, "naive" crop forecasts were constructed for those months prior to harvest and in which official forecasts are not made. The naive forecasts were constructed using the five-year moving average of past crop forecasts. This mechanism was used for two reasons. First, it uses data available to the marketplace; second, it tends to average out extreme harvests. Surprisingly, these forecasts, on average, are more accurate than the first official forecast for many countries and are not far off from the first official forecast in any country except those few where the forecast is made in the harvest month.

Insofar as the world market for wheat exhibits relatively free trade, it is the world production and its forecasts that are of ultimate economic concern. The world production and its forecasts of course are made up of individual country productions and their forecasts. This study uses the eleven major wheat producing countries\* for which monthly production forecasts are published on a fairly consistent basis in the Grain Bulletin. The aggregate production of the ten non-U.S. countries represents about 70 percent of non-U.S. world wheat production.

The forecasts for these ten countries were combined after filling in the gaps,\*\* and then the aggregated production figures were

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\*U.S.A., U.S.S.R., Canada, Argentina, India, Spain, France, Italy, U.K., Australia and South Africa.

\*\*By the continuation method described in Section A2.3.



inflated to 100 percent of non-U.S. world wheat. The source data are shown in Table A2.7 in millions of metric tons annually and in Table A2.8 in units of percentage of final revised estimates. As a convenient shorthand we will refer to the aggregated forecasts from the ten non-U.S. wheat-producing countries as the "Rest of the World."

The "forecasts" in Table A2.7 are not really forecasts in the usual sense of the word. They represent our estimates of what the market agents knew about the new wheat crop in each month of the period 1960 to 1974 based upon published forecast information and past experience. We calculated the forecast error mean and standard error of forecasts by subtracting the final production from each forecast figure and then calculating the sample mean and standard deviation of the differences. These results are shown in Table A2.9.

The LACIE Project Office in USDA's Foreign Agricultural Service is currently preparing a review and analysis of the accuracy of various USDA wheat forecasts for six of the seven foreign LACIE countries.\* The purposes of this study [7] are to determine:

1. In which countries and for what periods of time did the USDA system perform at least as well as the LACIE goals (i.e., 90 percent probability of 90 percent or better accuracy of production estimates at harvest)?
2. What were the relative sizes of the area and yield components of the production forecast mean square errors in each country?

Table A2.10 summarizes the preliminary results of the study expressed in terms of the probability of achieving 90 percent or better accuracy at six times of year related to the stages of crop development. These stages

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\* Argentina, Australia, Brazil, Canada, India and the Soviet Union. It was necessary to omit People's Republic of China due to lack of reliable data on wheat production in China.

Table A2.7 Historical Aggregated "Rest of the World" Wheat  
Production Forecasts (1960 to 1974)

In Millions of Metric Tons Annually							
Year	Month						Final
	MAY	JUNE	JULY	AUG	SEPT	OCT	
1961	178.75	178.75	178.75	178.75	178.75	178.75	
1962	183.76	183.76	183.18	185.04	174.89	172.74	
1963	182.90	182.90	188.47	188.47	203.06	202.35	
1964	192.19	192.19	189.62	192.62	200.92	201.63	
1965	189.05	189.05	189.05	190.91	193.77	193.77	
1966	195.91	195.91	199.34	201.20	209.07	208.49	
1967	199.34	199.34	199.77	199.77	208.07	208.35	
1968	206.64	210.64	215.93	215.93	212.07	215.07	
1969	218.65	218.65	218.65	218.65	228.23	227.37	
1970	235.66	242.81	242.81	242.81	243.24	243.39	
1971	239.67	235.52	235.52	235.52	228.51	227.66	
1972	250.82	250.82	250.82	250.82	259.26	260.26	
1973	252.54	253.68	254.68	254.11	264.12	264.69	
1974	272.42	272.42	275.28	272.56	272.56	269.84	
	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	
1961	178.75	178.75	177.32	177.32	177.32	178.18	153.30
1962	172.74	172.74	172.74	172.74	172.74	174.89	153.15
1963	202.35	202.06	203.35	204.06	204.92	204.92	184.18
1964	199.63	200.63	202.77	205.92	205.92	205.92	165.02
1965	193.77	193.77	198.91	201.20	201.20	202.63	194.48
1966	209.07	207.21	205.21	204.78	193.91	191.91	177.03
1967	207.92	208.64	210.64	209.78	211.21	263.26	231.23
1968	231.09	231.66	228.23	228.09	228.09	228.23	201.77
1969	231.37	231.37	231.37	230.80	230.80	233.95	237.67
1970	243.10	245.96	245.96	246.25	245.25	245.25	215.22
1971	227.94	243.39	239.81	240.24	240.10	240.10	224.37
1972	260.26	259.12	259.12	257.54	257.54	257.54	245.67
1973	264.69	265.12	266.12	270.27	270.27	264.98	255.68
1974	269.84	288.86	288.86	289.15	289.15	289.15	296.15

Table A2.8 Historical Aggregate "Rest of the World" Wheat  
Production Forecasts (1960 to 1974)

As Percentage of Final Revised Estimate						
Year	Month					
	MAY	JUNE	JULY	AUG	SEPT	OCT
1961	116.60	116.60	116.60	116.60	116.60	116.60
1962	119.98	119.98	119.61	120.82	114.19	112.79
1963	99.30	99.30	102.33	102.33	110.25	109.86
1964	116.46	116.46	114.90	116.72	121.75	122.18
1965	97.21	97.21	97.21	98.16	99.63	99.63
1966	110.66	110.66	112.60	113.65	118.09	117.77
1967	86.21	86.21	86.39	86.39	89.98	90.11
1968	102.41	104.39	107.02	107.02	105.10	106.59
1969	92.00	92.00	92.00	92.00	96.03	95.67
1970	109.50	112.82	112.82	112.82	113.02	113.09
1971	106.82	104.97	104.97	104.97	101.85	101.47
1972	102.10	102.10	102.10	102.10	105.53	105.94
1973	98.77	99.22	99.61	99.38	103.30	103.52
1974	91.98	91.98	92.95	92.03	92.03	91.12
	NOV.	DEC.	JAN.	FEB.	MAR.	APR.
1961	116.60	116.60	115.67	115.67	115.67	116.23
1962	112.79	112.79	112.79	112.79	112.79	114.19
1963	109.86	109.70	110.40	110.79	111.26	111.26
1964	120.97	121.58	122.88	124.78	124.78	124.78
1965	99.63	99.63	102.28	103.46	103.46	104.19
1966	118.09	117.04	115.91	115.67	109.53	108.40
1967	89.92	90.23	91.09	90.72	91.34	113.85
1968	114.53	114.81	113.11	113.04	113.04	113.11
1969	97.35	97.35	97.35	97.11	97.11	98.44
1970	112.96	114.29	114.29	114.42	113.95	113.95
1971	101.59	108.48	106.88	107.07	107.01	107.01
1972	105.94	105.47	105.47	104.83	104.83	104.83
1973	103.52	103.69	104.08	105.70	105.70	103.64
1974	91.12	97.54	97.54	97.63	97.63	97.63

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Table A2.9 Forecast Error Analysis for Rest of the World				
Month	Change (%)		Absolute (%)	
	Mean	Std.Error	Mean	Std.Error
May	-0.26	1.12	3.59	9.84
June	-0.53	1.19	3.85	9.97
July	-0.56	1.29	4.38	9.74
August	-1.52	3.67	4.94	10.20
September	0.32	1.17	6.46	9.52
October	-0.57	2.12	6.14	9.53
November	-0.96	2.37	6.71	9.56
December	0.12	1.29	7.66	8.82
January	-0.26	0.73	7.54	8.54
February	0.37	1.61	7.80	8.78
March	-1.56	5.86	7.43	8.43
April	8.99	7.30	8.99	7.30

occur in different months according to the latitude of the crop growing area. Referring to the wheat production estimates only, it is apparent from the table that only Canada comes up to the 90/90 at-harvest LACIE goals (although Australia does achieve better than 90/90 after harvest). Furthermore, some countries, such as Brazil and U.S.S.R., show very poorly at harvest, and even after harvest. In the case of the U.S.S.R., the USDA statistics on Area to be Harvested for Wheat are extremely good at all times after planting, thus indicating that major improvements would have to be made in the yield component. Unfortunately, the analysis of Russian wheat forecasts is based on data from only the three years 1973-1975, since the inception of the FAS/ERS Task Force. Another cautionary point is in order: A strong linear time trend has existed over the past ten years for the area of spring wheat (about two-thirds of total wheat area in U.S.S.R.). When this trend breaks, as it

Table A2.10 Relative Quality of USDA Wheat Estimates (1966-1975)  
by Time in Growing Season for Six LACIE Foreign Countries  
(percent probability of 90% or better accuracy)

Country	Pre-Planting	Post-Emergence	Mid-Season	Pre-Harvest	At Harvest	After Harvest
<u>1. Production</u>						
Argentina		44		33		
Australia	25	30		74	81	99
Brazil	5	8		31	31	54
Canada		26		45	94	56
India	56		64			88
USSR		23	27	31	34	65
<u>2. Area to be Harvested</u>						
Argentina		88		98		94
Australia		79		84		98
Brazil	21	31		48	44	40
Canada		51		96	99.9	
India	71		89		84	93
USSR		97.1	97.4	97.7	99.9	99.9
<u>3. Probable Yield</u>						
Argentina		69		41		92
Australia		28		68	94	99.7
Brazil	81	12		33	38	49
Canada		52		64	99	80
India	71		76		83	97
USSR		21	22	22	31	65

Source: LACIE Project Office draft report, February 1977 [7].

surely will at some point in the future, forecasting spring wheat area to be harvested in the U.S.S.R. will not be such an easy task.

Aggregation of the LACIE forecasts of wheat production for these six countries to a R.O.W. total wheat supply estimate will result in a less satisfactory set of statistics for input to the benefit model than those which we have used in Chapter 2 because there are less countries. For the sake of comparison, we show in Table A2.11 the aggregated R.O.W. supply estimates based on the six LACIE countries analyzed in [7] and the corresponding mean error and standard error of percentage deviations of the forecasts from the final estimates. We have used the same method of filling out the table as we used earlier with the Grain Bulletin Statistics.



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## APPENDIX A3 FORECAST DATA FROM THE GRAIN BULLETIN

In order to prepare the statistical description of the current information system given in Chapter 2, it was necessary to obtain historical time series of wheat production forecasts for the period 1960 to 1974. This data was obtained by ECON from 180 monthly issues of GRAIN BULLETIN published by Commonwealth Secretariat in London, U.K. On the basis of their regular appearance in this publication, ten foreign countries were selected to form a database for Rest of the World production forecasts:

U.S.S.R., Argentina, Spain, Canada, India, United Kingdom, South Africa, France, Australia and Italy.

Other countries, such as Brazil, Turkey and China, which we would have liked to include, were not represented sufficiently often in Grain Bulletin. The total average wheat production in the ten countries constituted about 70 percent of the Rest of the World production for 1960 to 1976.

As described in Appendix A2, the initial forecasts were calculated by ECON from five-year moving averages of the final estimates in previous years. Also forecasts, once published, were continued in subsequent months if a new forecast was not published in those months. This was the method used to generate a complete set of monthly "forecasts" for 1960 to 1974, which was required by the economic models.

The final estimates of national wheat production for any particular crop year vary slightly between different publications by USDA/FAS, the United Nations' Food and Agriculture Organization, the Commonwealth Secretariat and other official agencies concerned with grain production statistics. Sometimes these estimates vary between different issues of the same

publications, and even between contemporaneous documents of one and the same organization. Table A3.1 presents a comparison of selected Canadian wheat production final estimates for 1960 to 1976 from three USDA sources, one United Nations source and one previous ECON study. While agreement is good in all years except 1973 and 1974 (revisions may still be occurring in these recent statistics), there clearly are slight differences scattered throughout the table. Canada was not chosen to emphasize these differences; on the contrary, some much larger discrepancies can be expected in the case of nations which present a "more difficult" estimation task than Canada. For the purposes of this study, however, it will be seen that reasonable choices between alternative estimates of the same production figure have been made.

Table A3.1 Comparison of Various Final Estimates of Canadian Wheat Production					
Crop Year	(1) FAS- OMB Baseline Record <sup>1</sup> (7/28/76)	(2) FAS Circular No. M-249 <sup>2</sup> February 1973	(3) USDA ERS/FAS Grain Database (7/12/76) <sup>3</sup>	(4) United Nations FAO 1969 Production Yearbook	(5) ECON Report No. 76-122-1B January 1976 <sup>4</sup> (divided by 1.43) <sup>5</sup>
(in millions of metric tons)					
1960		14.108			14.126
1961		7.713			7.692
1962		15.392			15.385
1963		19.689			19.720
1964		16.341		16.349	16.294
1965		17.674		17.674	17.692
1966	22.516	22.516		22.516	22.517
1967	16.137	16.137		16.137	16.084
1968	17.688	17.685	17.688	17.686	17.692
1969	18.367	18.623	18.265		18.601
1970	9.024	9.024	9.025		9.021
1971	14.412	14.412	14.412		14.406
1972	14.514		14.412		14.476
1973	16.519		14.512		16.503
1974	13.295		16.159		14.266
<u>Notes:</u> <sup>1</sup> "Statistics Canada Final Estimates," according to the FAS unpublished document: "Comparison of Wheat Forecasts With Final Estimates: 1966-1975." <sup>2</sup> "Trends in World Grain Production: 1960 to 1972." <sup>3</sup> As quoted by Kenneth R. Farrell, Dep. Adm. of ERS in Table A.5 of USDA/ERS Report to Mr. Charles Miller, Office of Management and Budget, dated 10/26/76. <sup>4</sup> The January 1976 ECON Report erroneously scaled all national foreign production figures up by 1.43; hence, the correction in this table. <sup>5</sup> Based on 1960 through 1976 FAO Production Yearbooks.					

**Historical Forecasts (From Grain Bulletin) U.S.S.R.**  
(millions of metric tons)

YEAR	MAY	JUNE	JULY	AUG	SEPT	OCT	
1960	64.80	64.80	64.80	64.80	64.80	64.80	
1961	68.30	68.30	68.30	68.30	68.30	68.30	
1962	68.10	68.10	70.50	70.50	70.50	70.50	
1963	70.70	70.70	70.70	70.70	70.70	70.70	
1964	65.20	65.20	65.20	65.20	65.20	65.20	
1965	66.30	66.30	66.30	66.30	66.30	66.30	
1966	65.40	65.40	65.40	65.40	65.40	65.40	
1967	72.30	72.30	72.30	72.30	72.30	72.30	
1968	73.70	73.70	73.70	73.70	73.70	73.70	
1969	82.60	82.60	82.60	82.60	82.60	82.60	
1970	83.70	83.70	83.70	83.70	83.70	83.70	
1971	91.80	91.80	91.80	91.80	91.80	91.80	
1972	91.50	91.50	91.50	91.50	91.50	91.50	
1973	93.20	93.20	95.20	95.20	95.20	95.20	
1974	96.50	96.50	96.50	101.80	101.80	94.20	
	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	
1960	64.80	64.80	64.80	64.80	64.80	64.80	46.30
1961	68.30	68.30	68.30	68.30	68.30	68.30	51.70
1962	70.50	70.50	70.50	70.50	70.50	70.50	54.40
1963	70.70	70.70	70.70	70.70	70.70	70.70	40.00
1964	65.20	65.20	65.20	65.20	65.20	65.20	57.20
1965	66.30	66.30	66.30	66.30	59.00	58.00	46.30
1966	65.40	65.40	65.40	65.40	65.40	101.80	80.00
1967	82.50	82.50	82.50	82.50	82.50	82.50	64.20
1968	73.70	73.70	73.70	73.70	73.70	73.70	76.50
1969	82.60	82.60	82.60	82.60	82.60	82.60	62.30
1970	83.70	94.20	94.20	94.20	94.20	94.20	82.70
1971	91.80	91.80	91.80	91.80	91.80	91.80	81.90
1972	91.50	91.50	91.50	91.50	91.50	91.50	85.80
1973	95.20	108.90	108.90	108.90	108.90	108.90	109.80
1974	94.20	94.20	94.20	94.20	94.20	94.20	88.00

**Historical Forecasts (From Grain Bulletin) Argentina**  
(millions of metric tons)

YEAR	MAY	JUNE	JULY	AUG	SEPT	OCT	
1960	6.30	6.30	6.30	6.30	6.30	6.30	
1961	6.00	6.00	6.00	6.00	6.00	6.00	
1962	5.70	5.70	5.10	5.10	4.90	4.90	
1963	5.70	5.70	5.70	5.00	5.00	5.00	
1964	6.10	6.10	6.10	6.10	6.10	6.10	
1965	7.20	7.20	7.20	7.20	7.20	7.20	
1966	7.70	7.70	7.70	7.70	7.70	7.70	
1967	7.80	7.80	7.80	7.80	7.80	7.80	
1968	8.10	8.10	8.10	8.10	8.10	8.10	
1969	7.50	7.50	7.50	7.50	7.50	7.50	
1970	6.60	6.60	6.60	6.60	6.60	6.60	
1971	6.40	6.40	6.40	6.40	6.40	6.40	
1972	6.20	6.20	6.20	6.20	6.20	6.20	
1973	6.40	6.40	6.40	6.40	6.40	4.80	
1974	6.50	6.50	6.50	7.10	7.80	7.80	
	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	
1960	6.30	6.30	4.10	4.00	4.00	4.00	4.00
1961	6.00	6.00	6.00	6.00	6.00	5.20	5.20
1962	4.90	4.50	4.80	4.90	4.90	4.90	5.70
1963	5.00	5.00	6.30	7.10	7.10	7.10	8.90
1964	6.10	6.10	7.60	9.20	9.20	9.20	11.30
1965	7.20	5.70	5.70	5.70	5.70	5.70	6.20
1966	7.70	6.50	6.50	6.50	6.70	6.70	6.20
1967	8.50	8.50	7.80	7.40	7.40	7.40	7.30
1968	8.10	8.10	8.10	5.90	5.90	5.90	5.70
1969	7.50	7.50	7.50	7.50	6.70	6.70	7.00
1970	6.60	6.60	4.20	4.30	4.20	4.20	4.90
1971	6.40	5.20	5.20	5.20	5.00	5.00	5.70
1972	6.20	6.20	6.20	8.10	8.10	8.10	6.90
1973	4.80	4.80	4.80	5.80	5.80	5.80	6.60
1974	7.80	7.80	5.90	5.90	5.90	5.90	6.00

**Historical Forecasts (From Grain Bulletin) Spain**  
(millions of metric tons)

YEAR	MAY	JUNE	JULY	AUG	SEPT	OCT	
1960	4.50	4.50	4.50	4.50	4.50	4.50	
1961	4.40	4.40	4.40	4.40	3.30	3.10	
1962	4.30	4.30	4.30	4.30	4.30	4.30	
1963	4.30	4.30	4.40	4.50	4.50	4.50	
1964	4.40	4.40	4.40	4.10	4.10	4.10	
1965	4.50	4.50	4.40	4.20	4.20	4.20	
1966	4.60	4.60	4.80	4.80	4.80	4.80	
1967	4.80	5.10	5.10	5.10	5.40	5.30	
1968	4.80	4.80	4.80	4.80	5.50	5.50	
1969	4.90	4.90	4.90	4.90	4.90	4.90	
1970	4.90	4.00	4.00	4.00	4.00	4.00	
1971	4.90	4.90	4.90	4.90	5.20	5.40	
1972	5.00	5.00	5.00	5.00	4.60	4.50	
1973	5.00	5.00	5.00	5.00	5.00	5.00	
1974	3.90	3.90	3.90	3.90	4.70	4.50	
	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	
1960	4.50	4.50	4.50	4.50	4.50	4.50	3.50
1961	3.10	3.10	3.10	3.10	3.10	3.10	3.40
1962	4.30	4.30	4.30	4.30	4.90	4.90	4.80
1963	4.50	4.90	4.90	4.90	4.90	4.90	4.90
1964	4.10	4.10	4.10	4.10	4.00	4.00	4.00
1965	4.20	4.20	4.40	4.40	4.40	4.10	4.70
1966	4.80	4.80	4.80	4.80	4.80	4.80	4.80
1967	5.60	5.60	5.60	5.60	5.60	5.60	5.70
1968	5.50	5.50	5.50	5.70	5.70	5.70	5.50
1969	4.70	4.70	4.70	4.70	4.70	4.70	4.60
1970	3.70	3.70	3.70	3.70	3.70	3.70	4.10
1971	5.40	5.40	5.40	5.40	5.40	5.40	5.50
1972	4.50	4.50	4.50	4.60	4.60	4.60	4.60
1973	5.00	4.10	4.10	3.90	3.90	3.90	3.90
1974	4.50	4.50	4.50	4.50	4.50	4.50	4.40

**Historical Forecasts (From Grain Bulletin) Canada**  
(millions of metric tons)

YEAR	MAY	JUNE	JULY	AUG	SEPT	OCT	
1960	12.90	12.90	12.90	12.90	12.90	12.90	
1961	12.90	12.90	12.90	12.90	6.90	7.10	
1962	11.30	11.30	11.30	11.30	15.20	15.00	
1963	12.30	12.30	12.30	12.30	18.90	19.60	
1964	14.10	14.10	14.10	14.10	16.30	16.30	
1965	14.90	14.90	14.90	14.90	20.70	19.20	
1966	15.60	15.60	15.60	15.60	21.80	22.90	
1967	18.70	18.70	18.70	18.70	14.90	16.20	
1968	18.80	18.80	18.80	18.80	17.70	17.10	
1969	18.40	18.40	18.40	18.40	18.50	18.70	
1970	18.90	18.90	18.90	18.90	9.20	9.00	
1971	17.10	17.10	17.10	17.10	13.80	14.20	
1972	15.50	15.50	15.50	15.50	15.50	14.40	
1973	19.30	19.30	19.30	19.30	19.30	17.00	
1974	14.90	14.90	14.90	16.30	14.40	14.40	
	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	
1960	12.90	12.90	13.40	13.40	13.40	13.40	14.10
1961	7.10	7.10	7.10	7.10	7.10	7.10	7.70
1962	15.00	15.20	15.20	15.20	15.20	15.20	15.40
1963	19.70	19.70	19.70	19.70	19.70	19.70	19.70
1964	16.30	16.30	16.30	16.30	16.40	16.40	16.30
1965	19.20	19.20	18.80	18.50	18.50	18.40	17.70
1966	22.90	22.90	22.90	22.90	23.00	23.00	22.50
1967	16.20	16.20	16.20	16.20	16.20	16.20	16.10
1968	17.10	17.10	17.10	17.70	17.70	17.70	17.70
1969	18.70	18.70	18.70	18.70	18.70	18.70	18.60
1970	9.00	9.00	9.00	9.00	9.00	9.00	9.00
1971	14.20	14.30	14.30	14.30	14.30	14.30	14.40
1972	14.40	14.50	14.50	14.50	14.50	14.50	14.50
1973	17.00	17.10	17.10	17.10	17.10	17.10	16.50
1974	14.30	14.30	14.30	14.30	14.30	14.30	14.30

**Historical Forecasts (From Grain Bulletin) India**  
(millions of metric tons)

YEAR	MAY	JUNE	JULY	AUG	SEPT	OCT	
1960	9.20	9.20	9.20	9.20	9.20	9.20	
1961	9.50	9.50	9.50	10.80	10.80	10.80	
1962	9.90	9.90	10.80	10.80	11.80	11.80	
1963	10.50	10.50	8.60	11.80	11.80	11.80	
1964	11.00	11.00	11.00	9.70	9.70	9.70	
1965	11.00	11.00	11.00	11.00	11.00	12.10	
1966	11.50	11.50	11.50	11.50	11.50	11.50	
1967	11.30	11.30	11.30	11.30	11.30	11.30	
1968	11.10	11.10	11.10	11.10	16.60	16.60	
1969	12.30	17.30	17.30	17.30	17.30	17.30	
1970	14.10	14.10	14.10	14.10	20.10	20.10	
1971	15.70	15.70	15.70	15.70	23.30	23.30	
1972	18.40	18.40	18.40	18.40	25.10	25.10	
1973	21.50	21.50	21.50	21.50	21.50	21.50	
1974	25.00	25.00	25.00	25.00	25.00	25.00	
	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	
1960	9.20	9.20	9.20	9.20	9.20	9.20	10.30
1961	10.80	10.80	10.80	10.80	10.80	10.80	11.00
1962	11.80	11.80	11.80	11.80	11.80	11.80	12.00
1963	11.20	11.10	11.10	11.20	11.20	11.20	10.80
1964	9.70	9.70	9.70	9.70	9.70	9.70	9.90
1965	12.10	12.10	12.10	12.10	12.10	12.10	12.30
1966	11.50	11.50	11.50	10.70	10.70	10.70	10.70
1967	11.30	11.30	11.70	11.60	11.60	11.60	11.40
1968	16.60	16.60	16.60	16.60	16.60	16.60	16.50
1969	17.30	18.70	18.70	18.70	18.70	18.70	18.70
1970	20.10	20.10	20.10	20.10	20.10	20.10	20.10
1971	23.30	23.30	23.30	23.30	23.30	23.30	23.80
1972	25.10	25.00	25.60	26.50	26.50	26.50	26.40
1973	21.50	21.50	21.50	21.50	21.50	21.50	24.80
1974	25.00	25.00	22.10	22.10	22.10	22.10	22.10



Historical Forecasts (From Grain Bulletin) United Kingdom  
(millions of metric tons)

YEAR	MAY	JUNE	JULY	AUG	SEPT	OCT	
1960	2.80	2.80	2.80	2.80	2.80	2.80	
1961	2.90	2.90	2.90	2.90	3.80	2.40	
1962	2.80	2.80	2.60	2.60	3.70	3.40	
1963	3.10	3.10	3.10	3.70	2.80	2.80	
1964	3.20	3.20	3.20	3.20	3.40	3.40	
1965	3.40	3.40	3.40	4.00	3.90	3.90	
1966	3.60	3.60	3.60	3.60	3.50	3.50	
1967	1.30	3.80	3.80	3.80	3.90	3.80	
1968	3.70	3.70	3.70	3.70	3.70	3.70	
1969	3.80	3.80	3.80	3.80	3.80	3.80	
1970	3.70	3.70	3.70	3.70	3.70	3.70	
1971	3.80	3.80	3.80	3.80	3.80	3.80	
1972	4.00	4.80	4.80	4.80	4.80	4.80	
1973	4.20	4.20	4.20	4.90	4.90	4.90	
1974	5.00	5.00	5.00	5.40	5.80	5.60	
	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	
1960	2.80	2.80	2.80	3.00	3.00	3.00	3.00
1961	2.40	2.40	2.40	2.40	2.40	2.60	2.60
1962	3.40	3.60	3.60	3.70	3.70	3.70	4.00
1963	2.70	2.60	2.60	3.10	3.10	3.10	3.00
1964	3.40	3.40	3.40	3.40	3.70	3.70	3.80
1965	3.90	3.90	4.20	4.20	4.20	4.20	4.20
1966	3.50	3.50	3.50	3.60	3.60	3.60	3.50
1967	3.90	3.90	3.90	3.90	3.90	3.90	3.90
1968	3.70	3.70	3.70	3.70	3.70	3.70	3.50
1969	3.80	3.80	3.80	3.40	3.40	3.40	3.40
1970	4.20	4.20	4.20	4.20	4.20	4.20	4.20
1971	3.80	3.80	3.80	4.80	4.80	4.80	4.80
1972	4.80	4.80	4.80	4.80	4.80	4.80	4.80
1973	4.90	5.00	5.00	5.00	5.00	5.00	5.00
1974	5.60	5.60	6.10	6.10	6.10	6.10	5.80

Historical Forecasts (From Grain Bulletin) South Africa  
(millions of metric tons)

YEAR	MAY	JUNE	JULY	AUG	SEPT	OCT	
1960	0.80	0.80	0.80	0.80	0.80	0.80	
1961	0.80	0.80	0.80	0.80	0.80	0.80	
1962	0.80	0.80	0.80	0.80	0.80	0.80	
1963	0.80	0.80	0.80	0.80	0.80	0.80	
1964	0.80	0.80	0.80	0.80	0.80	0.80	
1965	0.90	0.90	0.90	0.90	0.90	0.90	
1966	0.90	0.90	0.90	0.90	0.90	0.90	
1967	0.80	0.80	0.80	0.80	0.80	0.80	
1968	0.90	0.90	0.90	0.90	0.90	0.90	
1969	1.00	1.00	1.00	1.00	1.00	1.00	
1970	1.00	1.00	1.00	1.00	1.00	1.00	
1971	1.20	1.20	1.20	1.20	1.20	1.20	
1972	1.40	1.40	1.40	1.40	1.40	1.40	
1973	1.50	1.50	1.50	1.50	1.50	1.50	
1974	1.60	1.60	1.60	1.60	1.60	1.60	
	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	
1960	0.80	0.80	0.80	0.70	0.70	0.70	0.80
1961	0.80	0.80	0.80	0.80	0.80	0.80	0.90
1962	0.80	0.80	0.70	0.70	0.70	0.70	0.70
1963	0.80	0.80	0.80	0.80	0.80	0.80	0.90
1964	0.80	0.80	0.80	0.80	0.80	0.80	1.10
1965	0.90	0.90	0.90	0.90	0.70	0.70	0.70
1966	0.60	0.60	0.60	0.60	0.60	0.60	0.60
1967	0.80	0.80	0.80	0.80	0.80	0.80	1.10
1968	0.90	0.90	0.90	1.20	1.20	1.20	1.30
1969	1.00	1.20	1.20	1.20	1.30	1.30	1.30
1970	1.00	1.20	1.20	1.40	1.40	1.40	1.40
1971	1.20	1.20	1.20	1.60	1.60	1.60	1.70
1972	1.40	1.80	1.80	1.80	1.80	1.80	1.70
1973	1.50	1.60	1.60	1.70	1.70	1.70	1.80
1974	1.60	1.60	1.50	1.50	1.50	1.50	1.80

Historical Forecasts (From Grain Bulletin) France  
(millions of metric tons)

YEAR	MAY	JUNE	JULY	AUG	SEPT	OCT	
1960	9.80	9.80	9.80	9.80	9.80	9.80	
1961	10.00	10.00	9.60	9.60	9.40	9.30	
1962	10.80	10.80	11.20	11.20	13.90	13.20	
1963	11.40	11.40	11.40	9.20	9.30	9.10	
1964	11.50	11.50	11.50	13.60	13.40	13.40	
1965	12.00	12.00	14.00	14.30	14.10	14.10	
1966	12.70	12.70	12.60	12.60	12.30	11.40	
1967	8.70	8.70	12.80	12.80	13.20	14.20	
1968	13.10	13.10	13.10	13.10	14.60	14.60	
1969	14.10	14.10	14.10	14.10	14.30	14.20	
1970	14.20	14.20	14.20	14.20	13.00	12.80	
1971	13.80	13.80	13.80	13.80	15.10	15.10	
1972	14.70	14.70	15.40	15.40	16.10	17.70	
1973	15.50	15.50	15.50	17.70	17.70	17.70	
1974	17.80	17.80	17.80	17.50	18.30	18.90	
	NOW.	DEC.	JAN.	FEB.	MAR.	APR.	
1960	9.80	9.80	10.90	10.90	10.90	10.90	11.00
1961	9.30	9.30	9.30	9.30	9.30	9.40	9.60
1962	13.20	13.90	13.90	13.90	13.90	13.90	13.90
1963	9.10	9.60	9.60	9.60	9.60	9.60	10.20
1964	13.40	13.40	13.40	13.40	13.60	13.60	13.80
1965	14.40	14.40	14.40	14.40	14.40	14.40	14.80
1966	11.40	11.40	11.40	11.30	11.30	11.30	11.30
1967	14.10	14.50	14.40	14.40	14.40	14.40	14.30
1968	14.90	14.90	14.90	14.90	14.90	14.90	15.00
1969	14.20	14.60	14.60	14.60	14.60	14.60	14.50
1970	12.80	12.90	12.90	12.90	12.90	12.90	12.90
1971	15.10	15.40	15.40	15.40	15.40	15.40	15.40
1972	17.70	17.70	17.70	17.70	17.70	17.70	18.10
1973	17.70	17.90	17.90	17.80	17.80	17.80	17.80
1974	18.90	18.90	18.90	18.90	18.90	18.90	18.90

Historical Forecasts (From Grain Bulletin) Australia  
(millions of metric tons)

YEAR	MAY	JUNE	JULY	AUG	SEPT	OCT	
1960	4.70	4.70	4.70	4.70	4.70	4.70	
1961	5.10	5.10	5.10	5.10	5.10	5.10	
1962	5.70	5.70	6.70	6.70	8.40	8.40	
1963	6.90	6.90	6.90	8.40	8.40	8.40	
1964	7.50	7.50	7.50	7.50	7.50	7.50	
1965	8.40	8.40	8.40	8.40	8.40	8.40	
1966	8.40	8.40	8.40	8.40	8.40	8.40	
1967	9.60	9.60	9.60	9.60	9.60	9.60	
1968	9.40	9.40	9.40	9.40	9.40	9.40	
1969	10.60	10.60	10.60	10.60	10.60	10.60	
1970	10.70	8.70	8.70	8.70	8.70	8.70	
1971	10.90	10.90	10.90	10.90	10.90	10.90	
1972	10.00	10.00	10.00	10.00	10.00	10.00	
1973	14.10	14.10	14.10	10.20	10.20	12.20	
1974	9.30	9.30	10.70	10.70	10.70	11.20	
	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	
1960	4.70	4.70	6.70	6.70	6.70	7.30	7.40
1961	5.10	5.10	5.10	5.10	5.10	6.70	6.70
1962	8.40	7.50	7.80	8.20	8.20	8.20	8.40
1963	7.80	7.80	8.00	8.80	8.80	8.80	8.90
1964	7.50	7.50	9.60	9.60	9.50	10.50	10.00
1965	8.40	8.40	6.90	6.90	6.80	6.80	7.10
1966	8.40	10.10	11.50	11.50	12.20	12.20	12.70
1967	9.60	9.60	7.10	7.50	7.50	7.60	7.50
1968	11.90	11.90	11.90	12.40	12.40	14.60	14.80
1969	10.60	10.60	10.60	11.20	11.20	11.20	10.50
1970	8.70	8.70	8.50	8.50	8.50	8.50	7.90
1971	10.90	10.90	10.90	8.40	8.40	8.40	8.60
1972	10.00	10.00	10.00	10.00	10.00	6.40	6.60
1973	12.20	12.20	12.20	11.50	11.50	11.50	12.00
1974	11.20	11.20	11.20	11.20	11.20	11.20	11.40

**Historical Forecasts (From Grain Bulletin) Italy**  
(millions of metric tons)

YEAR	MAY	JUNE	JULY	AUG	SEPT	OCT	
1960	9.20	9.20	9.20	9.20	9.20	9.20	
1961	8.60	8.60	8.60	8.60	7.90	7.90	
1962	8.50	8.50	8.50	8.50	8.50	9.20	
1963	8.70	8.70	8.70	8.30	8.30	8.30	
1964	8.40	8.40	8.40	9.20	9.00	9.00	
1965	8.40	8.40	8.90	9.50	9.50	9.50	
1966	9.00	9.00	9.20	9.20	9.20	9.20	
1967	9.20	9.20	8.80	8.80	9.10	9.10	
1968	9.30	9.30	9.30	9.30	9.40	9.40	
1969	9.60	9.60	9.60	9.60	9.60	9.60	
1970	9.80	9.80	9.80	9.80	9.80	9.60	
1971	9.80	9.80	9.80	9.80	9.80	9.90	
1972	9.90	9.90	9.90	9.50	9.50	9.50	
1973	9.80	9.80	9.80	8.90	8.90	8.90	
1974	8.90	8.90	8.90	9.70	9.70	9.60	
	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	
1960	9.20	9.20	6.80	6.80	6.80	6.80	6.80
1961	7.90	7.90	7.90	7.90	7.90	8.30	8.30
1962	9.20	9.20	9.60	9.50	9.50	9.50	9.50
1963	8.10	8.10	8.10	8.10	8.10	8.10	8.10
1964	9.00	9.00	9.00	9.00	8.60	8.60	8.60
1965	9.60	9.60	9.80	9.80	9.80	9.80	9.80
1966	9.20	9.20	9.20	9.40	9.40	9.40	9.40
1967	9.10	9.10	9.60	9.60	9.60	9.60	9.60
1968	9.40	9.40	9.40	9.60	9.60	9.60	9.70
1969	9.60	9.60	9.60	9.60	9.60	9.60	9.60
1970	9.60	9.60	9.70	9.70	9.70	9.70	9.70
1971	9.90	9.90	9.90	9.90	10.10	10.10	10.00
1972	9.50	9.40	9.50	9.50	9.50	9.40	9.40
1973	8.90	8.90	8.90	9.00	9.00	9.00	8.90
1974	9.60	9.60	9.60	9.60	9.60	9.60	9.60

***ECON Corporate Headquarters:***

Princeton, New Jersey  
Telephone 609-924-8778

***Western Office:***

San Jose, California  
Telephone 408-249-6364